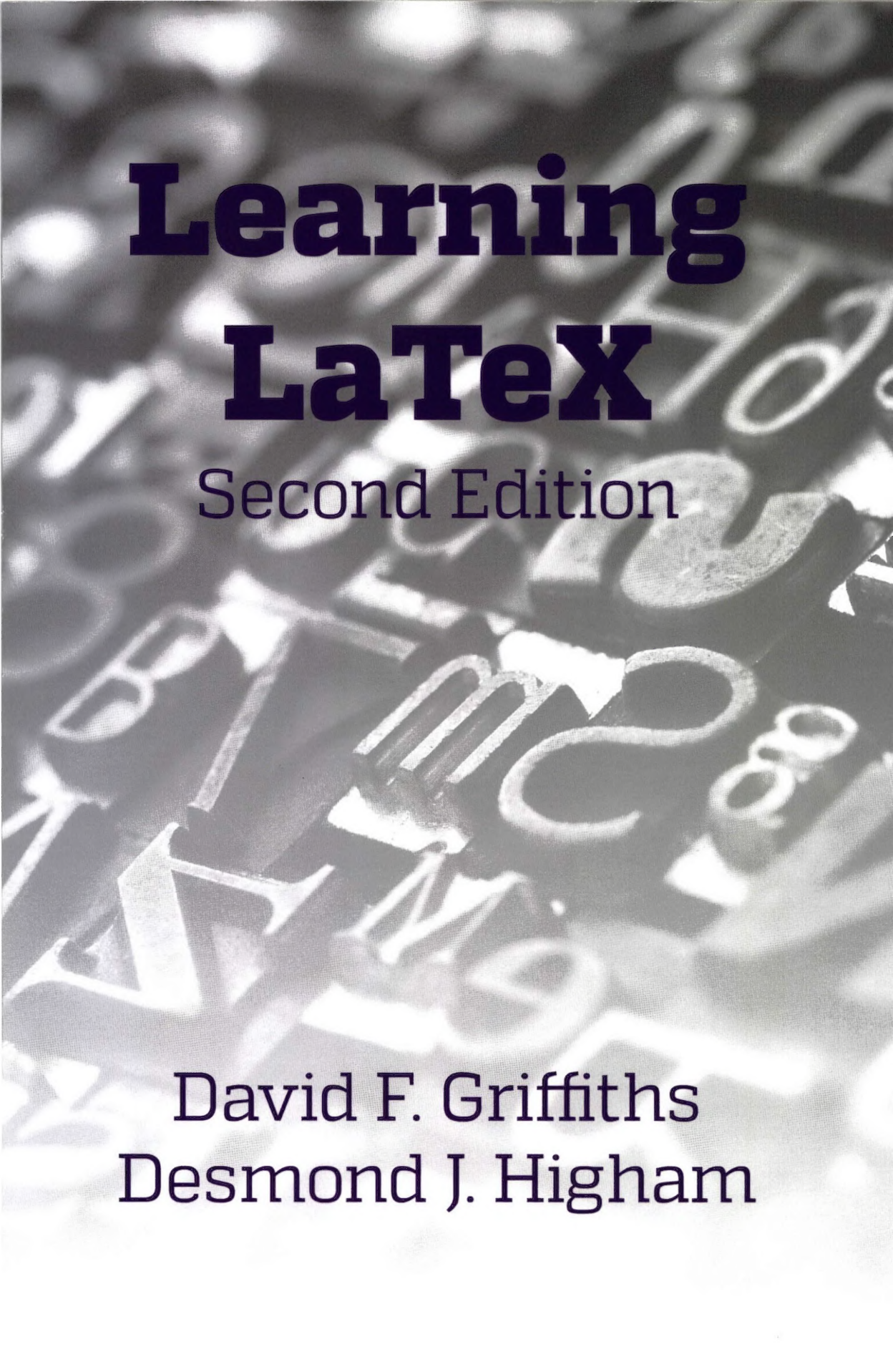

Learning LaTeX

Second Edition

David F. Griffiths
Desmond J. Higham

Do you need equations in your document? Close Equation Editor and learn LaTeX—the de facto standard for typesetting mathematics. Griffiths and Higham have updated their concise and example-filled LaTeX introduction to include bibliographies, posters, presentation slides, and essential online resources. The text is perfect for both self-study starting with the basics and a short introductory course for students at any level.

— Paul G. Constantine, *Colorado School of Mines*

For years, my only system for training students to LaTeX has been to hand them a copy of *Learning LaTeX* and to tell them to start writing. This has worked without fail for dozens of students. I never would have thought it possible, but the new edition is a substantial improvement with the additional coverage of BiBTeX, Beamer, and posters. *Learning LaTeX* should be handed to new graduate students in mathematical sciences along with their office key and ID card.

— Don Estep, *Colorado State University*

Here is a short, well-written book that covers the material essential for learning LaTeX. It includes incisive examples that teach LaTeX in a powerful yet abbreviated fashion. This manual includes the following crucial features:

- numerous examples of widely used mathematical expressions;
- complete documents illustrating the creation of articles, reports, presentations, and posters;
- troubleshooting tips to help you pinpoint an error;
- details of how to set up an index and a bibliography; and
- information about online LaTeX resources.

This second edition of the well-regarded and highly successful book includes new material on

- the American Mathematical Society packages for typesetting additional mathematical symbols and multiline displays;
- the BiBTeX program for creating bibliographies;
- the Beamer package for creating presentations; and
- the a0poster class for creating posters.

David F. Griffiths, now retired, originally trained as an applied mathematician and, after a brief spell at New York University, spent his academic career at the University of Dundee specializing in the numerical solution of differential equations. He has published 3 books and over 50 scientific articles on differential equations. David was joint organizing secretary of the Dundee Biennial Conferences on Numerical Analysis from 1983 to 2005.

Des Higham is a numerical analyst at the University of Strathclyde in Glasgow. He has research interests in stochastic computation, network science, and city analytics. He is a SIAM Dahlquist Prize winner, a SIAM Fellow, and a Fellow of the Royal Society of Edinburgh.

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More praise for *Learning LaTeX:*

Learning LaTeX by Higham and Griffiths is a wonderful, clear, short, and simple introduction to LaTeX. It is particularly well suited for undergraduate or postgraduate students in engineering, science, and mathematics who would like to learn LaTeX quickly without reading lengthy works of reference. Readers should be ready to write their first LaTeX document within just a few hours!

The material in the book is well structured and presented with many concrete and coherent examples. The authors start with a motivation on why one should learn LaTeX and how it is run and move from basic LaTeX commands via mathematical typesetting to features like inserting pictures and making bibliographies. A strength of the book is the appendix with concise samples of an article, a report, a presentation, and a poster (the latter two are new features of the second edition). Should readers wish to do so, they can go straight to these samples and use them as templates for their own documents.

A very comprehensive book and an easy read which I strongly recommend for both absolute beginners as well as for experienced users as a work of reference due to an excellent index.

— Melina Freitag, *University of Bath*

Hurrah, my favorite beginner's guide to LaTeX has been updated and improved and is as concise and fresh, and funny, as ever. It has been near my computer since its first release in the previous century. David and Desmond (whose friendly headshots can be found on the sample poster) will get you and your students up to speed with, as they correctly claim, "a minimum of fuss," and great examples and handy templates.
\LaTeX\ \rule s, still.

— Margot Gerritsen, *Stanford University*

There is something for everyone—from LaTeX beginner to experienced LaTeXnicians—in this excellent and entertaining book. The examples are punchy and drive straight to the point to get people using LaTeX the way it was meant to be used. The authors highlight many small issues and typographical faux pas without preaching. *Learning LaTeX* is comprehensive and covers all of the elements of LaTeX that you are likely to encounter in the vast majority of standard use. I cannot imagine a better reference for anyone!

— David F. Gleich, *Purdue University*

A quick-start guide for LaTeX beginners that will have readers off and TeX-ing in no time. Highly recommended for newbies, though veterans will also appreciate it as an essential reference. There are many examples throughout *Learning LaTeX*, and the appendices feature detailed examples of an article, a report, a beamer presentation, and a poster. Everyone will enjoy the light-hearted section on "LaTeX Through the Years." Highly recommended as part of every professor's lending library and every student's essentials.

— Tamara G. Kolda, *Sandia National Labs*

Learning LaTeX

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Second Edition

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Desmond J. Higham

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To Anne and Catherine

Contents

Preface

In this book you will find a brief introduction to the LaTeX system for typesetting documents. LaTeX, usually pronounced "lay-teck," is widely used throughout science and engineering. It is available, free of charge, for most operating systems.

Because of its popularity, every year there is a new batch of students and researchers who want to pick up the rudiments of LaTeX. Although many books have been written about LaTeX, we feel that there is a niche for a short, lively introduction that covers the essential material, while avoiding unnecessary detail. (In practice, most LaTeX users get by with a small vocabulary of commands.)

The book is aimed squarely at beginners to LaTeX who wish to learn the basics with a minimum of fuss. Our main target audience is students and early career researchers faced with the prospect of producing a report, thesis, article, presentation, or poster for the first time. Previous incarnations of this book were used in undergraduate and postgraduate classes at the University of Dundee, the University of Strathclyde, and the International Centre for Mathematical Sciences in Edinburgh, and we have found the treatment to be suitable for a short course on mathematical typesetting with LaTeX (typically two hours of lectures and three hours of supervised computer laboratories). The first edition of this book was still proving popular 20 years after it was written, even though certain parts were looking dated. Following encouragement from the publishing team at SIAM, we have therefore produced this updated second edition.

We firmly believe that the best way to teach LaTeX is by example. Hence, a large part of the book consists of "before and after" illustrations showing the effect of LaTeX commands. Feedback on the first edition has made it clear to us that our intended readership values conciseness. So, in completely revising and updating the book, we have continued to be ruthless with the page count. In addition to refreshing our references to the online world, we have added significant new material on

- packages made available by the American Mathematical Society, including support for typesetting mathematical symbols and multiline displays (commands from these packages are indicated by ($\mathcal{AMS}$) in the index);

- the BibTeX program for creating a bibliography;

- the `beamer` package for creating presentations;
- the `a0poster` class for creating posters.

To maintain the humor-to-content ratio, there is also some extra nonsense at the end of Chapter 5.

The book is organized as follows. Chapter 1 motivates LaTeX, introduces the key high-level concepts, and points to other available resources.

Chapter 2 deals with common low-level formatting commands, and Chapter 3 covers mathematical typesetting. Essential high-level commands are introduced in Chapter 4, which also gives tips on troubleshooting. In Chapter 5, more advanced issues are treated, including the use of packages.

Examples of complete LaTeX documents are provided in Appendix A and Appendix B, and the production of slides and posters is treated in Appendix C and Appendix D. Finally, Appendix E lists some LaTeX-related websites. The source files for the documents in Appendices A–D are available for download from SIAM's web page for this book, www.siam.org/books/OT148.

The first edition was prepared when both authors were at the University of Dundee. We thank the support staff, particularly Nick Dawes, for their technical expertise. Penny Davies commented on an almost-final version of the book, and numerous students provided feedback on the material. Nick Higham gave expert advice on many of the issues that we faced, and scrutinized several versions of the manuscript, including this new edition (on the implicit understanding that we would again refer to [5]).

Finally, we acknowledge the efforts of all those who have helped to make LaTeX such a valuable tool for the scientific community, especially Donald Knuth [7], Leslie Lamport [8], and the team members involved in the LaTeX3 Project.

David F. Griffiths
Desmond J. Higham

Scotland, July 1996
and July 2016

Chapter 1

Preamble

1.1 Should You Be Reading This Book?

Most potential readers of this book will have already heard something about LaTeX. Perhaps a friend or colleague recommended it to you, or maybe your professor advised you to learn about it. LaTeX is a computer typesetting system that specializes in producing mathematically oriented documents. It provides transparent access to the time-honored craft of mathematical typesetting and can be used to produce a range of documents, including class handouts, reports, letters, presentations, posters, theses, journal articles, and books.

We have written this book for LaTeX beginners, and we have striven to present a palatable and readable introduction, with a minimum of fuss and detail. The only prerequisite is a certain amount of computing experience. You should know how to use an editor and you should have the LaTeX package available. (Information about where to download LaTeX software can be found on page 87.) To appreciate the basic idea of controlling the output with a sequence of commands, experience with at least one programming language would be helpful.

In the interest of brevity and clarity, some of the things we say about LaTeX are a little incomplete and a vast amount is left unsaid. We hope that this book will build up your expertise to the extent that on those occasions when you need to know more, you will feel confident enough to consult one of the comprehensive references (see §1.4).

1.2 Motivation

There are several good reasons for learning LaTeX.

- Mathematical formulas can be produced quite easily. TeX [7], the program underneath LaTeX, knows a great deal about formatting mathematics, and hence your documents will look polished.
- Equations, citations, figures, tables, etc., can be labeled, so that cross-referencing is automated.

- LaTeX is installed at many universities and research institutions and can be run on most operating systems. The program, plus many add-on enhancements written by enthusiasts throughout the world, is freely available online. Commercial versions have also been produced for tablets and smartphones.

- The `tex` files have a plain format. They can, therefore, be produced using your favorite text editor and then be shared conveniently with your friends and colleagues whatever operating system they may be using.

- The `pdf/dvi` files produced by the system can be sent to a variety of output devices, including the computer screen and virtually all types of printers.

- LaTeX skills will prove useful if you are pursuing an academic career. Many journals now encourage authors to submit manuscripts in LaTeX.

LaTeX is not a WYSIWYG (What You See Is What You Get) system. Hence it lacks the obvious attraction of a real-time display of the formatted output. However, the alternative *logical design* approach of LaTeX offers advantages for most scientific authors. Scientific documents contain structures like sections, subsections, computer program listings, theorems, and mathematical equations. LaTeX forces you to think in terms of these structures, rather than concentrating on the appearance of the final product. In other words, your creative efforts are focused on content rather than style. Having created the document, you can completely alter its appearance by changing a small number of formatting commands. For example, it is a simple matter to change the size of the typeface or to move from one to two columns per page.

A word of warning is in order. LaTeX makes it possible to produce an impressive-looking document that is riddled with mistakes and inconsistencies. Hence, you should not be deceived by the aesthetics of the output. When you write a scientific document, your main concern should be to present your ideas clearly and correctly. LaTeX has been designed to relieve you of the burden of typesetting, so that you can concentrate on the substance. If you wish to learn more about *writing* in the mathematical sciences, then we recommend [5], which covers a range of topics such as choosing notation, formatting equations, English usage, punctuation, revising a draft, writing a presentation, and publishing a paper. It also discusses computing aids such as filters, pipes, and spellcheckers.

1.3 Running LaTeX

The precise details of how to run LaTeX depend upon the type of computer that you are using. Your local system administrator (or, if you installed the program yourself, the accompanying documentation) should tell you what commands to use. However, the general approach is common to all versions—you must create a file with a `tex` extension, let us call it `first.tex`. This file contains

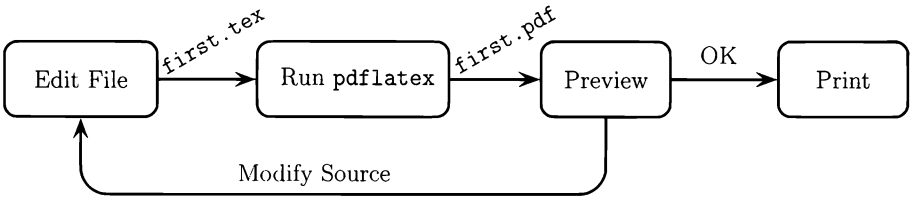


Figure 1.1: The sequence of commands for generating a `pdf` document from a `tex` file.

the text of your document, interspersed with commands that tell LaTeX how it is to be formatted. The contents of the file `first.tex` do not depend on your computer system—the same file is valid for all systems. On most systems, the command to run LaTeX on `first.tex` in a "terminal session" is

```
pdflatex first.tex
```

which produces the file `first.pdf`. This can be displayed on screen—referred to as *previewing*—or sent to a printer. In addition to `first.pdf`, files with extensions `aux` and `log` are created. (Other files with extensions such as `toc`, `idx`, and `bbl` may also be generated.) These can all safely be ignored at this stage!

The process of producing a typeset document involves repeatedly cycling through these steps, as illustrated in Figure 1.1. This process is considerably simplified with certain text editors (such as those that come bundled with standard LaTeX distributions) as they will run `pdflatex` and display the formatted document with a click of a button or a simple sequence of keystrokes (for example, Ctrl+t in the TeXworks editor in MiKTeX under Microsoft Windows or ⌘+t in the TeXShop editor in MacTeX under Mac OS X on an Apple device).

If PostScript graphics are to be included in the document, then the appropriate command for running LaTeX is

```
latex first.tex
```

which produces the file `first.dvi`. The extension `dvi` stands for *device independent*. This file can be understood by any one of several output devices; in particular it can be displayed on screen or sent to a printer (usually by converting to a `pdf` file). A bundled editor will provide a menu to choose between `pdflatex` or `latex` commands and will conflate the actions of formatting, converting, and previewing.

1.4 Resources

The authoritative LaTeX references are [8, 9]. Lamport's book [8] is a comprehensive manual; the first few chapters give a detailed, but relatively gentle, introduction, and the latter part constitutes a complete technical

specification. The encyclopedic [9] is packed full of information about LaTeX and the many packages that are available for its customization and extension. Anyone who uses LaTeX regularly ought to have access to [8] or [9].

Many other guides to LaTeX have been written. It is our belief that, having mastered the fundamentals of LaTeX outlined in this book, the interested reader will be sufficiently well equipped to pass directly to [8] or [9] without recourse to any "intermediate level" guides.

By far the most valuable resource is a friend, colleague, or teacher who is skilled in LaTeX. Seeking advice from fellow humans and studying chunks of relevant LaTeX will help greatly in your ascent of the learning curve.

A third source of information is the Internet, as discussed in Appendix E.

Chapter 2

Basic LaTeX

2.1 Sample Document and Key Concepts

We begin with an example. Illustrated on the next page is a LaTeX document generated from the source file `example.tex`. The contents of the file are reproduced on the left, and the box on the right shows the output produced when the file is run through LaTeX and displayed. We follow this convention throughout the book: raw LaTeX on the left, output on the right. Of course, rather than appearing in a little box, your output will be formatted in full-size pages.

If you glance through the raw LaTeX on the left of the next page (and at this stage you shouldn't look too carefully at the details), you will see various extra words preceded by the "backslash" character "\" such as `\begin{equation}` and `\end{equation}`, and special characters like `$`, `^`, and `_`. These tell LaTeX how to format the document. LaTeX knows a large number of formatting commands, but we hope to make it clear in this book that most situations can be handled with a relatively small subset.

You will also notice the lines

```
\documentclass{article}

\begin{document}
```

at the beginning of the file and

```
\end{document}
```

at the end. Lines like these must appear in every LaTeX document, and their use is discussed in §4.1. The rest of the examples in the book are to be regarded as small chunks of LaTeX that live inside a complete document, and hence they will not include these commands. Extra commands are sometimes placed between `\documentclass` and `\begin{document}`; this part of the document is known as the *preamble* (see Figure 4.1 on page 43).

```
\documentclass{article}

\begin{document}

This is a short document
to illustrate the basic use of
\LaTeX.

Simply leave a blank line to
get a new paragraph;
indentation is automatic.

Mathematical expressions
such as $y = 3 \sin x$
are obtained with dollar signs.
Equations can be displayed,
as in
\[
  y = 3 \sin x.
\]
Numbered equations are also
possible:
\begin{equation}\label{equa}
  y' = 3 \cos x.
\end{equation}
Because we have labeled this
equation we can refer to it
without having to know its
number.  Thus, the preceding
equation was
number~(\ref{equa}).

Powers (superscripts), as in $x^2$,
are obtained with \verb"^";
more complicated powers must live
in curly braces: $x^{2+\alpha}$.

Likewise, subscripts are obtained
with the underscore: $y_3$ or
$y_{n+1}$.

We use both in $x_{n+1}^{2+\alpha}$.

\end{document}
```

This is a short document to illustrate the basic use of LaTeX.

Simply leave a blank line to get a new paragraph; indentation is automatic.

Mathematical expressions such as $y = 3 \sin x$ are obtained with dollar signs. Equations can be displayed, as in

$$y = 3 \sin x.$$

Numbered equations are also possible:

$$y' = 3 \cos x. \tag{2.1}$$

Because we have labeled this equation we can refer to it without having to know its number. Thus, the preceding equation was number (2.1).

Powers (superscripts), as in x^2, are obtained with ^; more complicated powers must live in curly braces: $x^{2+\alpha}$.

Likewise, subscripts are obtained with the underscore: y_3 or y_{n+1}.

We use both in $x_{n+1}^{2+\alpha}$.

LaTeX generally regards groups of characters separated by spaces as *words*; a "newline" generated by the Return (or Enter) key is also thought of as a space. The number of spaces between words is immaterial—the output will look the same with one or twenty. Also, since a single "newline" character is treated as an interword space, it doesn't matter where newlines occur in the file; LaTeX will make up its own mind about how to break a paragraph into lines, hyphenating words if necessary to produce neat output.

A blank line—or any number of blank lines together—signifies the end of a paragraph. Judicious use of blank lines and spaces makes your `tex` file much easier to read and understand. A paragraph is automatically indented by LaTeX, except when it is the first in a section. If you want to override this feature, insert the `\noindent` command at the start of the new paragraph.

The following characters have a special meaning in LaTeX:

```
\  &  $  %  ~  _  {  }  #  ^
```

In case you really want one of these characters to appear in the output, most of them can be generated by preceding the character with a backslash.

```
The special characters \&, \$,
\%, \_, \{, \}, and \# may be
printed by preceding each with
a backslash. We can then put
text in \{curly braces\}.
```

The special characters &, $, %, _, {, }, and # may be printed by preceding each with a backslash. We can then put text in {curly braces}.

If a % sign is included in a line without being preceded by a backslash, the remainder of the line is ignored. This provides a mechanism for inserting comments into the LaTeX file. Look at the next example carefully and compare the input with the output.

```
It is likely that 50\% of the time
you will be frustrated because you
forgot to precede the % symbol by
a backslash.
```

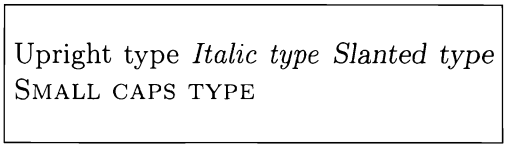
It is likely that 50% of the time you will be frustrated because you forgot to precede the a backslash.

The special characters (and ordinary characters, too) can also be displayed in a typewriter font using the `\verb` command. For example, `\verb+%~and\+` produces `%~and\`. The character immediately following `\verb`, in this case `+`, acts as the opening delimiter—everything will be printed out "verbatim" up to the next occurrence of that character. The text between the delimiters should not be broken across lines in the source file. For this reason, `\verb` is suitable only for short bursts of verbatim output.

2.2 Type Style

For variation and emphasis, the style of the type can be altered. More precisely, you can control the *shape*, *series*, and *family* of the type. There are four shapes

```
\textup{Upright type}
\textit{Italic type}
\textsl{Slanted type}
\textsc{Small caps type}
```

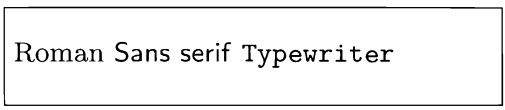


and two series

```
\textmd{Medium}
\textbf{Boldface}
```

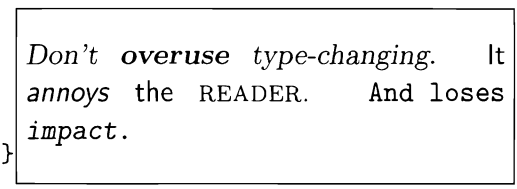
and three families

```
\textrm{Roman}
\textsf{Sans serif}
\texttt{Typewriter}
```



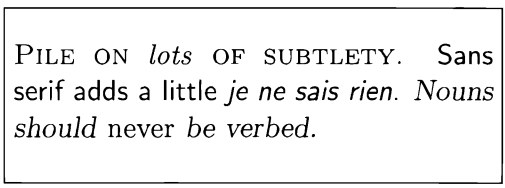
Note that the text whose type is to be changed is enclosed in curly braces after the command. You can combine the three features, as in

```
\textsl{Don't \textbf{overuse}
            type-changing.}
\textsf{It \textit{annoys} the
          \textsc{reader}.}
\texttt{And loses \textsl{impact}.}
```



In addition, LaTeX has the `\emph` command that causes the enclosed text to be emphasized. So `\emph{important}` becomes *important.* The particular effect produced by `\emph` depends on the type in current use.

```
\textsc{Pile on \emph{lots}
        of subtlety.}
\textsf{Sans serif adds a little
       \emph{je ne sais rien}.}
\textsl{Nouns should \emph{never}
        be verbed.}
```

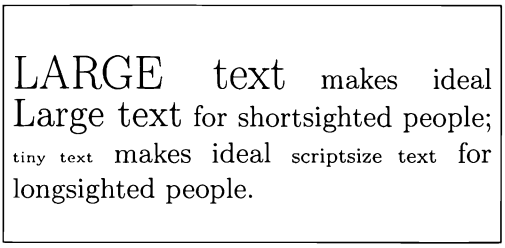


Characters of different sizes are sometimes needed for titles, headings, etc. The default size is 10 points, a point being a printing term for approximately 1/72 of an inch. To produce an entire document in a different type size, the `11pt` or `12pt` options can be specified with `\documentclass`, as discussed in §4.1. The declarations

```
\Huge \huge \LARGE \Large \large \normalsize
\small \footnotesize \scriptsize \tiny
```

can be used to change the size selectively. These declarations, and the words to which they apply, are enclosed in curly braces to limit their scope. A space separates the command from the text.

```
{\LARGE LARGE text} makes ideal
{\Large Large text} for
shortsighted people;
{\tiny tiny text} makes
ideal {\scriptsize
scriptsize text} for
longsighted people.
```



If the particular combination of shape, series, family, and size is not available on your system, LaTeX will warn you and substitute a "nearby" alternative.

2.3 Environments

Environments are portions of the document that we wish LaTeX to treat differently from the main body. They are generally created by enclosing the text between the commands

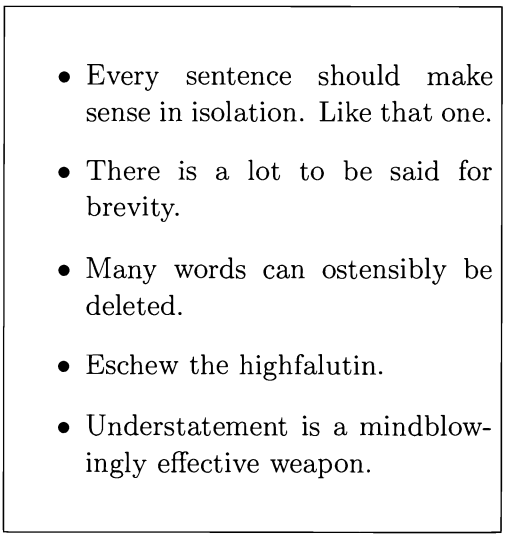
`\begin{`*environment name*`}`
...
`\end{`*environment name*`}`.

In this section we discuss some common nonmathematical environments.

2.3.1 Lists

There are several list-making environments. The `itemize` version produces "bullets."

```
\begin{itemize}
  \item Every sentence should
   make sense in isolation.
   Like that one.
  \item There is a lot to be
   said for brevity.
  \item Many words can
   ostensibly be deleted.
  \item Eschew the
   highfalutin.
  \item Understatement is a
   mindblowingly effective
   weapon.
\end{itemize}
```



Notice how each new entry is preceded by the `\item` command.

Numbered lists are produced with `enumerate`.

```
\begin{enumerate}
  \item Spellcheckers are not
   perfect; they can kiss my errs.
  \item Somebody once said
   that all quotes should be
   accurately attributed.
  \item The importance of
   comprehensive
   cross-referencing will be
   covered elsewhere.
\end{enumerate}
```

1. Spellcheckers are not perfect; they can kiss my errs.
2. Somebody once said that all quotes should be accurately attributed.
3. The importance of comprehensive cross-referencing will be covered elsewhere.

In the `description` environment an optional argument enclosed in square braces after the `\item` command can be used to customize the headings. The optional argument is set in a bold typeface.

```
\begin{description}
  \item[Rule 1.] Mixed
   metaphors can kill two
   birds without a paddle.
  \item[Rule 2.] Similes
   are about as much use
   as a chocolate teapot.
  \item[Rule 3.] Sporting
   analogies won't even
   get you to first base.
\end{description}
```

Rule 1. Mixed metaphors can kill two birds without a paddle.

Rule 2. Similes are about as much use as a chocolate teapot.

Rule 3. Sporting analogies won't even get you to first base.

Lists can be nested.

```
\begin{enumerate}
  \item Punctuation
   \begin{enumerate}
      \item Don't use commas, to
       separate text unnecessarily.
      \item Avoid ugly abr'v'ns.
   \end{enumerate}
  \item Spelling
   \begin{enumerate}
     \item If there's a particular
      word you can never spell,
      use a pnemonic.
     \item Take care with pluri.
   \end{enumerate}
\end{enumerate}
```

1. Punctuation
   (a) Don't use commas, to separate text unnecessarily.
   (b) Avoid ugly abr'v'ns.
2. Spelling
   (a) If there's a particular word you can never spell, use a pnemonic.
   (b) Take care with pluri.

2.3.2 Centering

The `center` environment places text in the center of the line. The \\ command signals the end of a line.

```
\begin{center}
  {\large\textbf{Assignment 1}}\\
  Sue d'Onym\\
  MS601
\end{center}
The answers to questions ....
```

Assignment 1
Sue d'Onym
MS601

The answers to questions ....

The spacing between successive lines in this example may be changed as described on page 15; commands for the automatic construction of titles for documents are described on page 40.

2.3.3 Tables

There are two environments related to tables. The first, called `tabular`, produces the table, and the second, `table`, is used to give the table a caption and a possible key for cross-referencing.

The `tabular` environment has the form

```
\begin{tabular}{format}
...
\end{tabular}
```

where the format tells LaTeX the number of columns and whether they should be left justified (`l`), centered (`c`), or right justified (`r`).

```
The marks for the 2016 class
are more respectable.

\begin{tabular}{lrc}
  Name & Mark & Grade \\
  \hline
  Emma Winner     & 99 & A+ \\
  Scott Passmark  & 51 & C \\
  Shirley Knott   &  5 & F
\end{tabular}

The average mark is well over 50\%.
```

The marks for the 2016 class are more respectable.

Name	Mark	Grade
Emma Winner	99	A+
Scott Passmark	51	C
Shirley Knott	5	F

The average mark is well over 50%.

Notice that

- the `{lrc}` specifies that the first column should be `l`eft justified, the second `r`ight justified, and the third `c`entered,
- the entries across each row of the table are separated by `&`,
- each line except the last terminates with \\,

- a horizontal line was created by placing `\hline` after the `\\` command,
- blank lines precede and follow the tabular environment so that the table lives in its own paragraph (otherwise the table would be formatted as part of the surrounding text),
- the table is left justified on the page.

Vertical lines can be drawn by including `|` at appropriate points in the format specification. In the next example we also center the table on the page.

```
\begin{center}
 \begin{tabular}{|l||r|c|}
   \hline
   Name & Mark & Grade \\
   \hline\hline
   Emma Winner    & 99 & A+\\
   Scott Passmark & 51 & C\\
   Shirley Knott  &  5 & F\\
   \hline
 \end{tabular}
\end{center}
```

Name	Mark	Grade
Emma Winner	99	A+
Scott Passmark	51	C
Shirley Knott	5	F

To obtain entries that span more than one column of a table we use `multicolumn`, as in the following example.

```
  \begin{tabular}{|l||r|r|}
   \hline
   & \multicolumn{2}{c|}{Marks}\\
         \cline{2-3}
   Name           & MS601& MS602\\
   \hline\hline
   Emma Winner    & 99 & 51\\
   Scott Passmark & 51 & 50\\
   Shirley Knott  &  5 & 49\\
   \hline
  \end{tabular}
```

	Marks	
Name	MS601	MS602
Emma Winner	99	51
Scott Passmark	51	50
Shirley Knott	5	49

The `\multicolumn` command has three arguments. The first specifies how many columns it should span, the second whether to left justify, right justify, or center the entry (notice the presence also of the `|` which ensures that the border of the surrounding box is complete), and the third contains the content. We have also introduced another command, `\cline{2-3}`, which draws the horizontal line through columns 2 to 3. For a line spanning a single column, use `\cline{2-2}`, for example.

The heading for a column often needs to be centered while the remaining contents are left (or right) justified. This can be accomplished using a `\multicolumn{1}{c}{...}` command that spans just one column. An illustration is provided by the second column of the next example.

```
\begin{tabular}{c l r @{.} l}
$x$ &\multicolumn{1}{c}{$e^{-x}$}
   & \multicolumn{2}{c}{$e^x$}
      \\\hline
1 & 0.368 & 2 & 718\\
2 & 0.135 & 7 & 389\\
4 & 0.0183 & 54 & 60\\
8 & 0.000335 & 2980 & \\\hline
\end{tabular}
```

x	e^{-x}	e^x
1	0.368	2.718
2	0.135	7.389
4	0.0183	54.60
8	0.000335	2980.

The values for e^x have been centered on the decimal point. This was achieved by placing the leading and trailing digits of the decimal numbers in separate columns and then using `@{.}` in the column format, which has the effect of replacing the intercolumn space by the decimal point. The corresponding heading has to span two columns so that `\multicolumn{2}{c}{...}` is appropriate. More generally, `@{`*argument*`}` replaces the intercolumn space with *argument*.

Occasionally, some further "fine tuning" is necessary. For instance the alignment of the data could be improved in the second and third columns of the table on page 12 that contains Grades. Had the marks all consisted of two digits, then the entire column could simply be centered. A solution is to fool LaTeX that this is the case by using the command `\phantom{...}`, which introduces an amount of space equivalent to the typeset form of its argument. Thus 5 is replaced by `\phantom{5}5`. Similarly, the grades C and F are replaced by `C\phantom{+}` and `F\phantom{+}`, respectively, in the following table.

```
\begin{center}
 \begin{tabular}{|l||c|c|}
   \hline
   Name & Mark & Grade \\
   \hline\hline
   Emma Winner    &99&A+\\
   Scott Passmark&51&C\phantom{+}\\
   Shirley Knott &\phantom{5}5 &
   F\phantom{+}\\
   \hline
 \end{tabular}
\end{center}
```

Name	Mark	Grade
Emma Winner	99	A+
Scott Passmark	51	C
Shirley Knott	5	F

Finally, we place the table in the `table` environment and give it a caption and a key. By designating a key in the caption with `\label{mytable}`, we can refer to this table anywhere in the document by `\ref{mytable}`, at which point the table number will be automatically inserted. The keys defined by `\label` can also be used for cross-referencing by page number with the command `\pageref`. Thus, with the key `tab:a` from the next table,

```
Table~\ref{tab:a} appears on page~\pageref{tab:a}.
```

produces "Table 2.1 appears on page 14."

```
The results given in
Table~\ref{tab:a} show the
very satisfactory performance
of the 2016 class, whose
average is over 50\%. (Note
that it is OK to refer to the
number of the table before it
appears.)

\begin{table}[b]
  \begin{center}
    \caption{Class Mark List}%
     \label{tab:a}
    \begin{tabular}{lcc}\hline
      Name & Mark & Grade \\
      \hline
      Emma Winner     & 99 & A+\\
      Scott Passmark  & 51 & C\phantom{+}\\
      Shirley Knott   &\phantom{5}5 & F\phantom{+}\\\hline
    \end{tabular}
  \end{center}
\end{table}
```

The results given in Table 2.1 show the very satisfactory performance of the 2016 class, whose average is over 50%. (Note that it is OK to refer to the number of the table before it appears.)

Table 2.1: Class Mark List

Name	Mark	Grade
Emma Winner	99	A+
Scott Passmark	51	C
Shirley Knott	5	F

The `table` environment (as well as `figure`, which we shall meet in §5.3) is a "floating environment" that is normally placed in the output document at roughly the location where it is input. Since tables and figures can be large objects, it may not be possible for LaTeX to fit them neatly onto the current page, so they are permitted to float to a more convenient location. The `[b]` on the command `\begin{table}[b]` for opening the table environment in the preceding example is an *optional* argument to tell LaTeX that you wish the table to appear at the bottom of page; other options are `[t]`, for top of page, `[h]`, for here (where it has been typed in), and `[p]`, which puts the table on a separate page containing other "floating bodies." It is possible to include more than one location specifier; `\begin{table}[thb]` tells LaTeX that your preferences are `t`, `h`, and `b`, in that order. The factors influencing LaTeX's table locating algorithm are many and various, and so your preferences may be overridden. Stricter adherence to your preferences can be signaled by the additional specifier `!` so that, for example, `[!b]` (almost) insists that the table appear at the bottom of the current page. For more details, see [8, §C.9.1].

To make the caption appear below the table, instead of above, place the `\caption` command immediately after the `\end{tabular}` command.

2.3.4 Verbatim

Verbatim is an extremely useful environment for displaying sections of computer code, raw LaTeX, etc., since it prints out the text exactly as it was input

and uses a (nonproportionally spaced) typewriter font. The special characters \&$%~_{}#^ lose their LaTeX significance within this environment.

```
\begin{verbatim}
% pattern.m
% Shaded region is where
% ||||x|-1|-1|-|||y|-1|-1||
%                   >=1/3

h = 0.05;   % grid spacing
[x,y] = meshgrid(-4:h:4,-4:h:4);
e = ones(size(x));
Z = abs( abs( abs( abs(x) - ...
       e) - e) - abs( ...
       abs( abs(y) - e) - e) );
spy(3*Z >= e);
\end{verbatim}
```

```
% pattern.m
% Shaded region is where
% ||||x|-1|-1|-|||y|-1|-1||
%                   >=1/3

h = 0.05;   % grid spacing
[x,y] = meshgrid(-4:h:4,-4:h:4);
e = ones(size(x));
Z = abs( abs( abs( abs(x) - ...
       e) - e) - abs( ...
       abs( abs(y) - e) - e) );
spy(3*Z >= e);
```

The alternative command `\verb`, which is more appropriate for short bursts of verbatim output, was discussed on page 7.

2.4 Vertical and Horizontal Spacing

The vertical spacing between lines can be altered using `\bigskip`, `\medskip`, and `\smallskip`. Compare the next example with that on page 11.

```
\begin{center}
  {\large\textbf{Assignment 1}}
  \medskip

  Sue d'Onym
  \smallskip

  MS601
\end{center}
\bigskip

The answers to questions ....
```

Assignment 1

Sue d'Onym

MS601

The answers to questions ....

When one of these commands occurs within a paragraph the space is added at the end of the next complete (formatted) line, which is why they have been followed by blank lines in the preceding example. The precise spacing caused by the three `skip` commands depends upon certain style parameters that are not discussed in this book.

Absolute vertical spacing is achieved with `\vspace`. The command

```
\vspace{2.2in}
```

will leave a vertical space of 2.2 inches, whereas `\vspace{3.5cm}` gives 3.5 centimeters. The `\vspace*` command forces LaTeX to insert the requested space when it might otherwise suppress it (for example, at the beginning of a new page). Other units of length are `mm` (millimeters), `em` (the width of the letter "M"—the widest character), `ex` (the height of the letter "x"), and `pt` for points. Negative lengths are permitted; `\vspace{-0.25in}` will cause the text following it to "move up" 0.25 inches. The command `\fill` represents an infinitely stretchable length. So, for example, `\vspace{\fill}` will produce a vertical gap that extends to the foot of the page (unless this `\fill` is competing with another infinitely stretchable `\fill`).

Horizontal spacing works in a similar way using the `\hspace` command.

```
Get out your rulers
and measure these lengths.
\vspace{0.2in}

Push right\hspace{1in}one inch.
\vspace{0.5cm}

Push right\hspace{\fill} hard.
\vspace{0.9cm}

Left\hspace{\fill} Middle
\hspace{\fill} Right.
```

Get out your rulers and measure these lengths.

Push right one inch.

Push right hard.

Left Middle Right.

Also available are two ready-made commands, `\quad` and `\qquad`, that provide horizontal space whose widths (`1em`: | | and `2em`: | |, respectively) depend on the size of the prevailing font. They can also be used within mathematical expressions—see page 29 for an example.

Other useful horizontal spacing commands for mathematical expressions are discussed on page 19.

Chapter 3

Typesetting Mathematics

3.1 Examples

The file `example.tex` on page 6 includes some simple mathematical typesetting. You will notice that mathematical symbols appear in an italic-like font; compare the correct form x, a, produced by `$x$, $a$`, with the regular roman type x, a. Single dollar signs enclose an in-line mathematical expression, whereas the delimiters `\[` and `\]` are used for unnumbered, displayed equations.

Some common mathematical symbols and the commands used to produce them are given in Tables 3.1 and 3.2. A mathematical symbol may be negated by preceding it with the `\not` command. Thus, `$\not<, \not\subset, \not|$` produces $\not<, \not\subset, \not|$. The commands `\ne`, giving $\ne$, and `\notin`, giving $\notin$, are already provided.

Mathematical functions such as "log" and "sin" are, by convention, typeset in standard roman type. This makes expressions easier to read; compare $\sin x$, $\cosh y$ with $sinx$, $coshy$. The former used the correct `$\sin x$, $\cosh y$` and the latter `$sin x$, $cosh y$`. Table 3.3 shows the built-in functions available in LaTeX. You may need another function, such as "diag," which is not available. In this case you can use the `\mathrm` command to produce roman type in a mathematical expression. For example,

```
$\mathrm{diag}(1,2,3,\ldots,20)$
```

gives $\mathrm{diag}(1, 2, 3, \ldots, 20)$. Further discussion of math fonts is given on pages 25 and 36.

The ellipsis "..." in the previous expression was produced using `\ldots`. Notice that the dots are aligned with the base of the characters. The form "$\cdots$" is produced by `\cdots`, which may only be used in math mode. This is more appropriate for use with $+, -, =$ as in $a_1 + a_2 + \cdots + a_n$; `\cdot` produces a single centered dot as in $a \cdot b$. Examples of vertical and diagonal ellipses are given on pages 23 and 24.

Table 3.1: The Greek letters and a selection of mathematical symbols. The last two rows of symbols will scale in size to fit the context.

\alpha	α	\beta	β	\gamma	γ	\delta	δ
\epsilon	ϵ	\varepsilon	ε	\zeta	ζ	\eta	η
\theta	θ	\vartheta	ϑ	\iota	ι	\kappa	κ
\lambda	λ	\mu	μ	\nu	ν	\xi	ξ
\pi	π	\varpi	ϖ	\rho	ρ	\varrho	ϱ
\sigma	σ	\tau	τ	\upsilon	υ	\phi	ϕ
\varphi	φ	\chi	χ	\psi	ψ	\omega	ω
\Gamma	Γ	\Delta	Δ	\Theta	Θ	\Lambda	Λ
\Xi	Ξ	\Pi	Π	\Sigma	Σ	\Upsilon	Υ
\Phi	Φ	\Psi	Ψ	\Omega	Ω		
\pm	$\pm$	\mp	$\mp$	\times	$\times$	\div	$\div$
\cap	$\cap$	\cup	$\cup$	\vee	$\vee$	\wedge	$\wedge$
\circ	$\circ$	\ast	$\ast$	\star	$\star$	\diamond	$\diamond$
\bigcirc	$\bigcirc$	\cdot	$\cdot$	\odot	$\odot$	\bullet	$\bullet$
\oplus	$\oplus$	\ominus	$\ominus$	\otimes	$\otimes$	\oslash	$\oslash$
\nabla	∇	|	$\|$	\prime	$\prime$	\surd	$\surd$
\partial	∂	\ell	ℓ	\Re	$\Re$	\Im	$\Im$
\infty	∞	\triangle	$\triangle$	\exists	$\exists$	\forall	$\forall$
\imath	$\imath$	\jmath	$\jmath$	\emptyset	$\emptyset$	\backslash	$\backslash$
\le	$\le$	\ll	$\ll$	\geq	$\geq$	\gg	$\gg$
\subset	$\subset$	\subseteq	$\subseteq$	\supset	$\supset$	\supseteq	$\supseteq$
\in	$\in$	\ni	$\ni$	\notin	$\notin$	\propto	$\propto$
\ne	$\ne$	\equiv	$\equiv$	\approx	$\approx$	\sim	$\sim$
\perp	$\perp$	\parallel	$\parallel$	\cong	$\cong$	\simeq	$\simeq$
\sum	$\sum$	\prod	$\prod$	\int	$\int$	\oint	$\oint$
\bigcap	$\bigcap$	\bigcup	$\bigcup$	\bigoplus	$\bigoplus$	\bigotimes	$\bigotimes$

Table 3.2: A selection of arrows.

\leftarrow	$\leftarrow$	\longleftarrow	$\longleftarrow$	\downarrow	$\downarrow$
\Leftarrow	$\Leftarrow$	\Longleftarrow	$\Longleftarrow$	\Downarrow	$\Downarrow$
\rightarrow	$\rightarrow$	\longrightarrow	$\longrightarrow$	\uparrow	$\uparrow$
\Rightarrow	$\Rightarrow$	\Longrightarrow	$\Longrightarrow$	\Uparrow	$\Uparrow$
\leftrightarrow	$\leftrightarrow$	\longleftrightarrow	$\longleftrightarrow$	\updownarrow	$\updownarrow$
\Leftrightarrow	$\Leftrightarrow$	\Longleftrightarrow	$\Longleftrightarrow$	\Updownarrow	$\Updownarrow$
\nearrow	$\nearrow$	\rightleftharpoons	$\rightleftharpoons$	\searrow	$\searrow$
\swarrow	$\swarrow$	\mapsto	$\mapsto$	\nwarrow	$\nwarrow$

Table 3.3: Commands for typesetting mathematical functions.

\arccos	\cos	\csc	\exp	\ker	\limsup	\min	\sinh
\arcsin	\cosh	\deg	\gcd	\lg	\ln	\Pr	\sup
\arctan	\cot	\det	\hom	\lim	\log	\sec	\tan
\arg	\coth	\dim	\inf	\liminf	\max	\sin	\tanh

We continue with examples involving fractions, subscripts, and superscripts. The command `\frac` for formatting fractions has two arguments that are enclosed in curly braces (the numerator and denominator). Within matched dollar signs it should be used selectively (see page 35).

The characters `_` and `^` produce subscripts and superscripts, respectively. An expression involving more than one symbol can be used as a subscript or superscript if it is enclosed in curly braces.

```
\[
  u(x,t) = \sigma
     \frac{x-x_0}{1+\sigma t}
\]

\[
  v(x,t) = x-\sqrt{x^{2}+e^{a-2t}}
\]

\[
  S_n = a_1 + a_2 + \cdots + a_n
\]

\[
  a_n = 3 + (-1)^n, \;  n = 1,2,\ldots,N
\]
```

$$u(x,t) = \sigma\frac{x-x_0}{1+\sigma t}$$

$$v(x,t) = x - \sqrt{x^2 + e^{a-2t}}$$

$$S_n = a_1 + a_2 + \cdots + a_n$$

$$a_n = 3 + (-1)^n,\ n = 1, 2, \ldots, N$$

In the last equation above, the command `\;` adds horizontal spacing. LaTeX is very good at typesetting mathematics, but occasionally—as in the `\;` example above—it is necessary to help with the spacing. Horizontal spacing commands available in math mode include

Negative thin: `\!` || Thin: `\,` || Medium: `\:` || Thick: `\;` ||

where the distance between the vertical bars indicates the amount of space created in each case. (The normal amount of space between vertical bars is ||.) Apart from `\,` these commands can only be used in math mode. As an illustration, compare the following variants.

```
$ \sqrt{2} \sin x $

$ \sqrt{2} \, \sin x $

\bigskip

$ \int \int f(x,y) dxdy $

$ \int \!\! \int f(x,y) \,dx \, dy $
```

$\sqrt{2}\sin x$
$\sqrt{2}\,\sin x$

$\int\int f(x,y)dxdy$
$\iint f(x,y)\,dx\,dy$

In the double integral example, LaTeX does not automatically recognize that `dx` and `dy` are separate entities and treats `dxdy` as the product of four variables unless given extra help. A more satisfactory approach to multiple integrals is described on page 38.

Subscripts and superscripts are treated differently when they are attached to integral, summation, or product symbols or to lim, max, min, inf, or sup.

```
\[
  S_N = \sum_{j=1}^N a_j
\]

\[
  \int_{x=0}^\infty e^{-x^2} dx
        = \frac{\sqrt{\pi}}{2}
\]

\[
  \lim_{n\rightarrow\infty}
        (1+\frac{x}{n})^n = e^x
\]

\[
  \max_{1\le x\le 2}x +
         \frac{1}{x}
           = \frac{5}{2}
\]
\[
  \prod_{n=1}^{\infty} \frac{4n^2}{4n^2-1}=\frac{\pi}{2}
\]
```

$$S_N = \sum_{j=1}^{N} a_j$$

$$\int_{x=0}^{\infty} e^{-x^2} dx = \frac{\sqrt{\pi}}{2}$$

$$\lim_{n\rightarrow\infty} (1+\frac{x}{n})^n = e^x$$

$$\max_{1\le x\le 2} x + \frac{1}{x} = \frac{5}{2}$$

$$\prod_{n=1}^{\infty} \frac{4n^2}{4n^2-1} = \frac{\pi}{2}$$

Expressions like these look different if we change from a displayed equation to an in-line formula.

```
\begin{enumerate}
\item $S_N = \sum_{j=1}^N a_j$
\item $\int_{x=0}^\infty e^{-x^2}
      dx = \frac{\sqrt{\pi}}{2}$
\item $\lim_{n\rightarrow\infty}
        (1+\frac{x}{n})^n = e^x $
\item $\max_{1\le x\le 2}x +
      \frac{1}{x}= \frac{5}{2}$
\item $\prod_{n=1}^{\infty}
       \frac{4n^2}{4n^2-1}
            =\frac{\pi}{2}$
\end{enumerate}
```

1. $S_N = \sum_{j=1}^{N} a_j$
2. $\int_{x=0}^{\infty} e^{-x^2} dx = \frac{\sqrt{\pi}}{2}$
3. $\lim_{n\rightarrow\infty}(1+\frac{x}{n})^n = e^x$
4. $\max_{1\le x\le 2} x + \frac{1}{x} = \frac{5}{2}$
5. $\prod_{n=1}^{\infty} \frac{4n^2}{4n^2-1} = \frac{\pi}{2}$

These differences are further explored in §3.8.1.

Blank spaces typed into mathematical expressions have no effect—LaTeX has very firm ideas about how much space is required. You should exploit this flexibility by including spaces that make the input more readable.

3.2 Braces

The curly braces { and } have a special meaning in LaTeX; for example, we have seen how they enclose arguments for the `\frac` command. To make curly braces appear in mathematical expressions, we precede them with a backslash: `\{ ... \}`. If we use `\left\{ ... \right\}` instead of `\{ ... \}`, then LaTeX will automatically choose braces of an appropriate size. The same "autosizing" occurs with `\left[ \left( \left|` and `\right| \right) \right]` and all the delimiters shown in Table 3.4.

Table 3.4: A selection of delimiters.

(	(	)	)	[	[	]	]
\{	{	\}	}	\langle	⟨	\rangle	⟩
\uparrow	↑	\downarrow	↓	\Uparrow	⇑	\Downarrow	⇓
\updownarrow	↕	\Updownarrow	⇕	|	‖	\\|	‖
\lfloor	⌊	\rfloor	⌋	\lceil	⌈	\rceil	⌉

The appropriate use of large braces can improve both the appearance and the readability of complicated formulas.

```
\[
p(x) = 6 [ 1+(1+(\frac{1}{2}
         + \frac{1}{6}x)x)x ]
\]
\[
p(x) = 6 \left[ 1+\left(1+\left(
         \frac{1}{2}+\frac{1}{6}x
                \right)x    \right)x
         \right]
\]
```

$$p(x) = 6[1 + (1 + (\frac{1}{2} + \frac{1}{6}x)x)x]$$

$$p(x) = 6\left[1 + \left(1 + \left(\frac{1}{2} + \frac{1}{6}x\right)x\right)x\right]$$

Each `\left` must be accompanied by a `\right`, although the type of delimiter used need not be the same.

LaTeX also provides each delimiter in a number of fixed sizes. For example,

```
\[
( \big( \Big( \bigg( \Bigg(
   \qquad \Bigg\} \bigg] \big| )
\]
```

$$(\big(\Big(\bigg(\Bigg(\qquad \Bigg\}\bigg]\big|)$$

and

```
\[
p(x) = 6 \bigg( 1+\Big(1+ \big(
         \frac{1}{2}+\frac{1}{6}x
           \big)x   \Big)x  \bigg)
\]
```

$$p(x) = 6\bigg(1 + \Big(1 + \big(\frac{1}{2} + \frac{1}{6}x\big)x\Big)x\bigg)$$

where the parentheses are not quite so overpowering.

Limits of integration may be attached to braces by using sub/superscripts, as in the next example.

```
\[
  \int_0^1 x^n dx =
    \left[
      \frac1{n+1}x^{n+1}
    \right]_0^1=\frac1{n+1}
\]
```

$$\int_0^1 x^n dx = \left[\frac{1}{n+1}x^{n+1}\right]_0^1 = \frac{1}{n+1}$$

The square root symbol $\sqrt{}$, given by `\sqrt{...}`, also autosizes and accepts an optional argument in square braces; so `\sqrt{5}` gives $\sqrt{5}$ and `\sqrt[3]{5}` gives $\sqrt[3]{5}$.

```
Prove that, for $n \ge 1$,
\[
 \frac{1}{2} < \sqrt[n]{
    \left\{
 \frac{1\cdot3\cdots(2n-1)}
  {2\cdot4\cdots2n}\right\}} < 1.
\]
```

Prove that, for $n \ge 1$,

$$\frac{1}{2} < \sqrt[n]{\left\{\frac{1\cdot3\cdots(2n-1)}{2\cdot4\cdots2n}\right\}} < 1.$$

The size of the index n of the surd can be increased by typesetting it in `\scriptstyle` (the same style as a sub/superscript, see §3.8.1):

```
Prove that, for $n \ge 1$,
\[
 \frac{1}{2} <
    \sqrt[\scriptstyle n]{
    \left\{
      \frac{1\cdot3\cdots(2n-1)}
     {2\cdot4\cdots2n}\right\}} < 1.
\]
```

Prove that, for $n \ge 1$,

$$\frac{1}{2} < \sqrt[n]{\left\{\frac{1\cdot3\cdots(2n-1)}{2\cdot4\cdots2n}\right\}} < 1.$$

3.3 Arrays and Matrices

To format arrays and matrices (rectangular arrays of mathematical expressions), we use the `array` environment, which *must occur within* `$...$`, `\[...\]`, *or one of the mathematical environments* described in §3.5. Each row of the array must contain the same number of entries, separated by `&`. As with tables, all rows except the last are terminated with `\\`.

```
\[
  \begin{array}{llcr}
    a    & 0  & \sin (12x) & c  \\
   a+b   & 16 & \sin (2x)  & b+c \\
  a+b+c & 8  & \sin x     & a+b+c
  \end{array}
\]
```

$$\begin{array}{llcr} a & 0 & \sin(12x) & c \\ a+b & 16 & \sin(2x) & b+c \\ a+b+c & 8 & \sin x & a+b+c \end{array}$$

The choice `{llcr}` following the `\begin{array}` specifies that the first two columns should be left justified, the third centered, and the last right justified.

An array usually forms part of a more complicated mathematical expression and is often enclosed within "autosized" braces, such as `\left[` and `\right]`, described in the previous section.

```
The system may be
written in the matrix--vector
form $A u = e$, where
\[
A =
  \left[
    \begin{array}{ccc}
      1   & 1   & 1\\
      x   & y   & z\\
      x^2 & y^2 & z^2
    \end{array}
  \right], \;
\mathbf{u} =
  \left[
    \begin{array}{c}
      x \\ y \\ z
    \end{array}
  \right]
\]
and $\mathbf{e} = [1,1,1]^T$. The determinant of $A$ is given by
\[
\left|  \begin{array}{ccc}
    1   & 1   & 1\\
    x   & y   & z\\
    x^2 & y^2 & z^2
  \end{array} \right|  = (x-y)(y-z)(z-x),
\]
so $A$ is nonsingular precisely when the three values $x,y,z$
are distinct.
```

The system may be written in the matrix–vector form $Au = e$, where

$$A = \begin{bmatrix} 1 & 1 & 1 \\ x & y & z \\ x^2 & y^2 & z^2 \end{bmatrix}, \quad \mathbf{u} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

and $\mathbf{e} = [1,1,1]^T$. The determinant of A is given by

$$\begin{vmatrix} 1 & 1 & 1 \\ x & y & z \\ x^2 & y^2 & z^2 \end{vmatrix} = (x-y)(y-z)(z-x),$$

so A is nonsingular precisely when the three values x, y, z are distinct.

A submatrix can be highlighted by judicious use of the `\multicolumn` and `\cline` commands introduced in §2.3.3 for tables.

```
\[
 \left[
  \begin{array}{ccc}
   1 & 2 & 3\\\cline{2-3}
   4 & \multicolumn{1}{|c}{5}
       & \multicolumn{1}{c|}{6}\\
   7 & \multicolumn{1}{|c}{8}
       & \multicolumn{1}{c|}{9}\\\cline{2-3}
 \end{array}
\right]
\]
```

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & \boxed{5} & \boxed{6} \\ 7 & \boxed{8} & \boxed{9} \end{bmatrix}$$

The ellipses `\ldots` and `\cdots` mentioned on page 17, along with the vertical and diagonal versions `\vdots` and `\ddots`, are useful for formatting matrices.

```
The $N\times N$
tridiagonal matrix $T$,
defined by
\[
T = \left[
  \begin{array}{ccccc}
    a &  b   &  0  &\cdots& 0\\
    c &  a   &  b  &      &\vdots\\
    0 &\ddots&\ddots&\ddots& 0\\
   \vdots&    &  c  &  a   & b\\
    0 &\cdots&  0  &  c   & a
  \end{array}
  \right],
\]
has eigenvalues
\[
    \lambda_j = a + \sqrt{bc}\,
    \cos \frac{2\pi j}{N+1},\; 1 \le j \le N.
\]
```

The $N \times N$ tridiagonal matrix T, defined by

$$T = \begin{bmatrix} a & b & 0 & \cdots & 0 \\ c & a & b & & \vdots \\ 0 & \ddots & \ddots & \ddots & 0 \\ \vdots & & c & a & b \\ 0 & \cdots & 0 & c & a \end{bmatrix},$$

has eigenvalues

$$\lambda_j = a + \sqrt{bc}\,\cos\frac{2\pi j}{N+1},\ 1 \le j \le N.$$

Sometimes less is more. Removing some of the detail brings out the structure of the matrix more clearly.

```
\[
T = \left[
  \begin{array}{ccccc}
    a &  b   &      &      &  \\
    c &  a   &  b   &      &  \\
      &\ddots&\ddots&\ddots&  \\
      &      &  c   &  a   &  b\\
      &      &      &  c   &  a
  \end{array}
  \right].
\]
```

$$T = \begin{bmatrix} a & b & & & \\ c & a & b & & \\ & \ddots & \ddots & \ddots & \\ & & c & a & b \\ & & & c & a \end{bmatrix}.$$

If the $\mathcal{AMS}$ package[1] `amsmath` is loaded by including the command

```
\usepackage{amsmath}
```

in the preamble, then a number of shortcuts become available to produce matrices of up to 10 centered columns with a variety of delimiters. For example,

$$\begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}^{-1} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}^{T}, \quad \begin{vmatrix} 0 & -1 \\ 1 & 0 \end{vmatrix} = 1 = \begin{Vmatrix} 0 & -1 \\ 1 & 0 \end{Vmatrix}, \quad \begin{Bmatrix} 0 & -1 \\ 1 & 0 \end{Bmatrix}.$$

The first of these is produced by

```
\[
  \begin{bmatrix}
     0 & -1\\1 & 0
  \end{bmatrix}^{-1}
\]
```

[1] See §5.1 and Appendix E for more information on packages.

and must live in a mathematical environment, in this instance `\[...\]`. The remaining matrices were generated by replacing `bmatrix` by `pmatrix`, `vmatrix`, `Vmatrix`, and `Bmatrix`, respectively. In the last of these cases, we have indulged in a little fine-tuning by preceding the $(2,2)$ entry in the matrix by `\phantom{-}` (see page 13), which aligns the entries in the second column in a more pleasing fashion. Replacing `bmatrix` by `matrix` produces a matrix without any delimiters.

Finally, we give an example which allows small matrices to be integrated within the text with minimal effect on the line spacing.

```
If the complex number $z = a+i b$
is associated with the vector
$\left[\begin{smallmatrix}
     a\\b
 \end{smallmatrix}\right]$, then
the product $i z$ is associated
with the matrix--vector product
$\left[
     \begin{smallmatrix}  0 & -1\\ 1 &  \phantom{-}0 \end{smallmatrix}
 \right]
 \left[ \begin{smallmatrix}      a\\b     \end{smallmatrix}\right]$.
```

If the complex number $z = a + ib$ is associated with the vector $\left[\begin{smallmatrix} a \\ b \end{smallmatrix}\right]$, then the product iz is associated with the matrix–vector product $\left[\begin{smallmatrix} 0 & -1 \\ 1 & 0 \end{smallmatrix}\right] \left[\begin{smallmatrix} a \\ b \end{smallmatrix}\right]$.

Note that we have again used `\phantom{-}` to adjust the alignment of the second column.

3.4 Fonts, Hats and Underlining

The range of math symbols may be extended by typesetting them in a different font or by modifying them with hats, tildes, or underlining.

The following example illustrates some of the fonts that can be used in math mode. The calligraphic font `\mathcal` is available only for uppercase characters and `\mathbf` affects only *letters, numbers, and uppercase Greek letters*; letters are set in bold roman font rather than the italic font normally used for math symbols (this conforms to the usual convention for typesetting mathematics). We describe other ways of obtaining bold symbols on page 36.

```
$
 \mathrm{A,B,C,\ldots,x,y,z.}\\
 \mathbf{A,B,C,\ldots,x,y,z.}\\
 \mathbf{\Gamma,\ldots,\Omega,}
 \mathbf{\alpha,\ldots,\omega.}\\
 \mathsf{A,B,C,\ldots,x,y,z.}\\
 \mathit{A,B,C,\ldots,x,y,z.}\\
 \mathcal{A,B,C,\ldots,X,Y,Z.}
$
```

$\mathrm{A,B,C,\ldots,x,y,z.}$
$\mathbf{A,B,C,\ldots,x,y,z.}$
$\mathbf{\Gamma,\ldots,\Omega,}\mathbf{\alpha,\ldots,\omega.}$
$\mathsf{A,B,C,\ldots,x,y,z.}$
$\mathit{A,B,C,\ldots,x,y,z.}$
$\mathcal{A,B,C,\ldots,X,Y,Z.}$

The syntax of font-changing commands in math mode is similar to that for text mode (see page 8). However, the argument is processed in math mode, and consequently spaces are ignored. For example, `$\mathit{for all} x > 0$` gives "$\mathit{forall}x > 0$". Text can be interspersed in a math expression by using

\mbox so that \mbox{for all $x > 0$} gives "for all $x > 0$" (notice the space included after all within \mbox).

A range of hats and tildes are also provided to modify symbols in math mode and these are illustrated in Table 3.5. Unlike \underline and \overline, the wide symbols come in just two sizes and so do not necessarily fit their arguments. For example, $\widehat{u+v+w}$ gives $\widehat{u+v+w}$, while $\underline{u+v+w}$ gives $\underline{u+v+w}$. The \stackrel command stacks the first argument (in \scriptstyle—see page 22) above the second argument.

Table 3.5: Hats and underlining

\hat u	$\hat{u}$	\widehat u	$\widehat{u}$	\widehat{u+v}	$\widehat{u+v}$
\tilde u	$\tilde{u}$	\widetilde u	$\widetilde{u}$	\widetilde{u+v}	$\widetilde{u+v}$
\dot u	$\dot{u}$	\underline u	$\underline{u}$	\underline{u+v}	$\underline{u+v}$
\ddot u	$\ddot{u}$	\bar u	$\bar{u}$	\overline{u+v}	$\overline{u+v}$
\vec u	$\vec{u}$	\overline{\hat u +v}	$\overline{\hat{u}+v}$	\stackrel{\triangle}{=}	$\stackrel{\triangle}{=}$

The dots should be removed from the characters i and j if symbols are to be placed above them. The alternatives \imath,\jmath are provided for this purpose, and hence $\hat\imath, \tilde\jmath$ lead to $\hat{\imath}, \tilde{\jmath}$.

The \overbrace and \underbrace commands provide more elaborate ornamentation of expressions.

```
$x^{m}=y^{n}$ means that
\[
\underbrace{x\cdot x\cdots x}_m =
\overbrace{y\cdot y\cdots y}^n.
\]
```

$x^m = y^n$ means that

$$\underbrace{x \cdot x \cdots x}_{m} = \overbrace{y \cdot y \cdots y}^{n}.$$

Notice how sub/superscripts have been used to create the labels m and n. We return to this example on page 37.

3.5 Equation Environments

We have seen that a mathematical expression can be displayed by enclosing it in \[...\]. In this case we are using the displaymath environment and the expression is not numbered. In order to get a numbered expression, we must use the equation environment, which is contained in

\begin{equation} ...\end{equation}.

If we include a labeling command, as in \label{fermat}, we can refer to the equation by its key—\ref{fermat}—rather than its number. See the example involving \ref{equa} on page 6. Keys, whether they be for equations, tables, figures, or sections, must be unique. It is good practice to use keys with

a standard format to distinguish the objects that they label. For instance, `eq:pde` for an equation, `fig:circ` for a figure, and so on.

The environment

```
\begin{eqnarray} ...\end{eqnarray}
```

is provided to format sets of equations. This is essentially a table, in math mode, with precisely three columns formatted `{rcl}`, that is, right justified, centered, and left justified. Entries within a row are separated by `&`, and all rows except the last are terminated by `\\`. Each row of the array will be numbered (and may therefore be labeled), but numbering can be turned off by including `\nonumber` in the row. A complete set of unnumbered equations is obtained with

```
\begin{eqnarray*} ...\end{eqnarray*}
```

It is usual, but not essential, to align equations around a relational operator, such as $=$, $\leq$, or $\approx$.

```
\begin{eqnarray}
 y &=& x^4 + 4          \nonumber\\
   &=& (x^2+2)^2-4x^2 \nonumber\\
   &\le&(x^2+2)^2     \label{yineq}
\end{eqnarray}
```

$$\begin{aligned} y &= x^4 + 4 \\ &= (x^2+2)^2 - 4x^2 \\ &\leq (x^2+2)^2 \end{aligned} \tag{3.1}$$

This environment introduces too much space around the alignment character ($=$ in this case), and its use is now deprecated in favor of the many environments available in the $\mathcal{AMS}$ package `amsmath` that are designed to handle collections of equations and very long mathematical expressions. From this point forward, we shall assume that this package has been loaded as described on page 24.

Equations or expressions that require more than one line may be typeset using the `multline` environment. The division into separate lines is not automatic but has to be decided manually, as the next example reveals.

```
\begin{multline}\label{4thpower}
  (x+y)^4 = x^4+y^4\\
    +4xy(x^2+y^2)\\
    +6x^2y^2
\end{multline}
```

$$\begin{aligned} (x+y)^4 = x^4 + y^4 \\ + 4xy(x^2+y^2) \\ + 6x^2y^2 \end{aligned} \tag{3.2}$$

Only the last line is numbered—use `multline*` for an unnumbered equation.

The simplest environment for aligning equations is `align` (and its unnumbered cousin `align*`). It views the display as being composed of two columns, the leftmost column being right aligned, and vice versa, with no intercolumn space. The column separator is again an ampersand. Reformatting the system (3.1) with `align` gives (note that the `&` comes before the symbol to be aligned)

```
\begin{align}
 y &=  x^4 + 4          \nonumber\\
   &=  (x^2+2)^2-4x^2 \nonumber\\
   &\le (x^2+2)^2    \label{yineq2}
\end{align}
```

$$\begin{aligned} y &= x^4 + 4 \\ &= (x^2+2)^2 - 4x^2 \\ &\le (x^2+2)^2 \end{aligned} \tag{3.3}$$

The most striking difference is that `align` uses less space around the aligned symbols. This environment can deal with more than one column of equations:

```
\begin{align*}
y &=  +a, &  z &=  -a,\\
  &={}+a, &  z &={}-a,\\
  &= 1+b, &  z &= 1-b.
\end{align*}
```

$$\begin{aligned} y &= +a, & z &= -a, \\ &= +a, & z &= -a, \\ &= 1+b, & z &= 1-b. \end{aligned}$$

There is one `&` for each alignment point and one to separate consecutive equations. In general, any odd number of ampersands is allowed. This example also illustrates the different spacing that applies when using + and − as unitary ($+a$ and $-a$) and binary ($1+b$ and $1-b$) operators. In the middle row the + and − symbols are preceded by curly braces `{}`, which fool LaTeX into treating them in a binary fashion.

The `alignat` environment is designed for situations that require multiple alignment points. Unlike `align`, the `alignat` environment formats columns alternately as right- and left-justified and no space is added between any of the columns. It also requires an argument which sets the number of pairs of `rl` columns.

```
The ``triangular'' system
\begin{alignat*}{3}
&ax+{}&by&{}+cz &&=f\\
&bx+{}&cy&{}    &&=g\\
&cx   &  &      &&=h
\end{alignat*}
can be solved by substitution.
```

The "triangular" system

$$\begin{aligned} ax + by + cz &= f \\ bx + cy &= g \\ cx &= h \end{aligned}$$

can be solved by substitution.

Notice that we have again used `{}` to persuade LaTeX to treat the + symbols as binary operators.

Our second example of `alignat` introduces some new twists.

```
Two of the key axioms of the
arithmetic of natural numbers are:
\begin{alignat*}{2}
  p+q&=q+p \quad&&
        \text{commutative}\\
&&& \text{law of addition}\\
  pq&=qp  &&
        \text{commutative}\\
&&& \text{law of multiplication}
\end{alignat*}
```

Two of the key axioms of the arithmetic of natural numbers are:

$$\begin{aligned} p+q &= q+p && \text{commutative} \\ &&& \text{law of addition} \\ pq &= qp && \text{commutative} \\ &&& \text{law of multiplication} \end{aligned}$$

A `\quad` of space has been included between the second and third columns (to prevent them running into each other), and the third column has been left empty since it would be right justified. This example also used the `amsmath` command `\text{...}`, which temporarily leaves math mode and formats its argument in the normal roman text font. This command is similar to the LaTeX command `\mbox{...}` (see page 26) and respects any interword spaces in its argument but is more versatile since, unlike `\mbox{...}`, it adopts the appropriate font size when used in sub/superscripts (see page 37 for examples).

There are occasions when it is not appropriate to align multiline expressions, and the `gather` environment then comes into its own. Each line is centered and numbered, but in our example we use the starred version, leading to unnumbered equations.

```
Ramanujan produced a number
of approximations to
$\pi$. They included
\begin{gather*}
\frac{19}{16}\sqrt{7},\quad
\frac{7}{3}
\left(1+\frac{\sqrt{3}}{5}
    \right),\\
\left(9^2+\frac{19^2}{22}
    \right)^{1/4},
\quad
\frac{63}{25}
\left(\frac{17+15\sqrt{5}}
    {7+15\sqrt{5}}\right),
\end{gather*}
the last of which is accurate to 9 decimal places.
```

Ramanujan produced a number of approximations to π. They included

$$\frac{19}{16}\sqrt{7}, \quad \frac{7}{3}\left(1+\frac{\sqrt{3}}{5}\right),$$

$$\left(9^2+\frac{19^2}{22}\right)^{1/4}, \quad \frac{63}{25}\left(\frac{17+15\sqrt{5}}{7+15\sqrt{5}}\right),$$

the last of which is accurate to 9 decimal places.

3.5.1 Embedded Environments and Subequations

We continue our treatment of collections of equations by taking a brief look at other ways in which they can be grouped using the `amsmath` package. The books by Kopka and Daly [6] and Grätzer [3] may be consulted for the full range and greater detail.

The "stand-alone" environments `align`, `alignat`, and `gather` described in the previous section have the related environments `aligned`, `alignedat`,

and `gathered` which have to be positioned inside another math environment. These new environments can be regarded as blocks that can be referenced by a single number. This is an example that features `aligned`.

```
The differential equations
\begin{equation}\label{odes}
  \begin{aligned}
     x'(t)-\alpha x(t)&=y(t),\\
     y'(t)-\beta  y(t)&=f(t)
  \end{aligned}
\end{equation}
can be solved sequentially.
```

The differential equations

$$\begin{aligned} x'(t) - \alpha x(t) &= y(t), \\ y'(t) - \beta y(t) &= f(t) \end{aligned} \tag{3.4}$$

can be solved sequentially.

The `cases` environment occurs frequently and is built on the `aligned` environment.

```
The Kronecker delta is defined by
\[
\delta_{ij} =
    \begin{cases}
      1 & \text{when $i=j$}, \\
      0 & \text{when $i\ne j$}.
    \end{cases}
\]
```

The Kronecker delta is defined by

$$\delta_{ij} = \begin{cases} 1 & \text{when } i = j, \\ 0 & \text{when } i \neq j. \end{cases}$$

When there is a close relationship between equations, this can be reflected in the way they are numbered by using the

`\begin{subequations} ... \end{subequations}`

environment.

```
\begin{subequations}\label{all}
 The 2nd order recurrence relation
 \begin{equation}\label{rr}
   x_{n+2}+a x_{n+1}+b x_n=f_n
 \end{equation}
 is equivalent to the pair of
 first order recurrence relations
 \begin{equation}\label{pair}
   \left.\begin{aligned}
    x_{n+1}-\alpha x_n &= y_n\\
    y_{n+1}-\beta y_n  &= f_n,
   \end{aligned}\right\}
 \end{equation}
 where $\alpha$ and $\beta$ are
 the roots of
 \begin{equation}\label{qdrtc}
   r^2+ar+b=0.
 \end{equation}
\end{subequations}
```

The 2nd order recurrence relation

$$x_{n+2} + a x_{n+1} + b x_n = f_n \tag{3.5a}$$

is equivalent to the pair of first order recurrence relations

$$\left.\begin{aligned} x_{n+1} - \alpha x_n &= y_n \\ y_{n+1} - \beta y_n &= f_n, \end{aligned}\right\} \tag{3.5b}$$

where α and β are the roots of

$$r^2 + ar + b = 0. \tag{3.5c}$$

This environment contains a mixture of text and displayed equations which, in this example, have all been labeled. We can refer to the entire set of equations

using (`\ref{all}`) (giving (3.5)) or to an individual equation; for example, (`\ref{pair}`) gives (3.5b).

We have also used `\left.` instead of `\left\{` in this equation. This creates a "dummy" left brace. (Without the dummy, LaTeX would complain that `\right\}` did not have a matching partner.) Generally, `\left.` and `\right.` can be used to create a dummy partner for any autosized delimiter.

The `amsmath` package defines the command `\tag{...}` to enable the labeling of equations with words or symbols rather than numbers, while still allowing cross-referencing with `\label` and `\ref`. As well as a text argument, such as `\tag{linear}`, math symbols can be used if placed within dollar signs.

```
Suppose that
\begin{equation}\label{1st}
  \begin{aligned}
    x'(t)-\alpha x(t)&=y(t)\\
    y'(t)-\beta  y(t)&=f(t)
  \end{aligned}  \tag{$\dag$}
\end{equation}
and
\begin{equation}\label{2nd}
  x''(t)+ax'(t)+bx(t)=f(t).
\tag{$\ddag$}
\end{equation}
Then (\ref{1st}) and (\ref{2nd}) are equivalent if $\alpha$
and $\beta$ are the roots of $r^2+ar+b=0$.
```

Suppose that

$$\begin{aligned} x'(t) - \alpha x(t) &= y(t) \\ y'(t) - \beta y(t) &= f(t) \end{aligned} \qquad (\dagger)$$

and

$$x''(t) + ax'(t) + bx(t) = f(t). \qquad (\ddagger)$$

Then (†) and (‡) are equivalent if α and β are the roots of $r^2 + ar + b = 0$.

The tags are produced without braces if `\tag*` is used instead of `\tag`.

3.6 Customized Commands

LaTeX is a verbose language. Commands tend to be long strings that become tedious to type. To overcome this, we can define abbreviations using `\newcommand`, whose syntax is

`\newcommand{`*name*`}{`*definition*`}`.

```
\newcommand{\Dtn}{\Delta t_n}
Let $\Dtn := t_{n+1} - t_n$
denote the stepsize. Then the
local error is proportional
to $\Dtn^2$.
```

Let $\Delta t_n := t_{n+1} - t_n$ denote the stepsize. Then the local error is proportional to Δt_n^2.

In this example we have defined a command `\Dtn`. Once it has been defined, every subsequent occurrence of `\Dtn` will be equivalent to `\Delta t_n`. Making definitions in this way offers three distinct advantages. First, it is quicker to type the shortened version. Second, it is easier to understand and debug complicated expressions if they consist of neat units. Third, if we decide to

change our notation, then we need only alter the definition, rather than all occurrences of the symbol.

There is a major difference between the two definitions

```
\newcommand{\Dtna}{\Delta t_n}
\newcommand{\Dtnb}{$\Delta t_n$}
```

The first can be used only in math mode, as in `$\Dtna$`. The second however, must be used outside math mode, since, for example, `$\Dtnb$` is equivalent to `$$\Delta t_n$$`, which does not give the desired effect. This kind of difficulty can be avoided by using `\ensuremath`. If we have

```
\newcommand{\Dtn}{\ensuremath{\Delta t_n}}
```

then `\Dtn` is equivalent to `\Delta t_n` inside math mode and `$\Delta t_n$` outside math mode.

It is a common (but not universal) custom to typeset the mathematical constants e ($= 2.7183...$), i ($= \sqrt{-1}$) and the differential d (as in dx) in upright font to aid readability of formulas. Thus, with the definitions

```
\newcommand{\E}{\mathrm{e}}
\newcommand{\I}{\mathrm{i}}
```

we find that

```
Euler's celebrated formula
$e^{i\pi}=-1$ becomes
$\E^{\I\pi} = -1$.
```

Euler's celebrated formula $e^{i\pi} = -1$ becomes $\mathrm{e}^{\mathrm{i}\pi} = -1$.

The merit of using new commands in this way is that it is easy to revert to an italic font should the need arise.

It is possible to include one or more arguments in a definition. The number of arguments (if nonzero) appears inside square braces between the name and the definition. Suppose we make the definitions

```
\newcommand{\D}{\mathrm{d}}
\newcommand{\dbyd}[2]{\frac{\D#1}{\D#2}}
```

In the second case there are two arguments, signified by `[2]`. The `#1` and `#2` show where in the definition the first argument (`#1`) and second argument (`#2`) are to appear. When we use the definition, the required arguments are enclosed in curly braces.

```
The chain rule gives
\[
  \dbyd{y}{t} =
    \dbyd{y}{x}\times\dbyd{x}{t}.
\]
```

The chain rule gives

$$\frac{\mathrm{d}y}{\mathrm{d}t} = \frac{\mathrm{d}y}{\mathrm{d}x} \times \frac{\mathrm{d}x}{\mathrm{d}t}.$$

It is possible to provide an optional argument to a command, provided that it is the first argument. The general syntax is

`\newcommand{`*name*`}[`*number*`][`*optional value*`]{`*definition*`}`

There are three arguments in the following example, and the optional value of the first is the empty string (designated by `[]`). When the command is invoked with two arguments (both in curly braces) these are deemed to be the second and third, with the first argument taking its default value. When a different value is required for the first argument, it is enclosed in square brackets.

```
\newcommand{\dnbyd}[3][]%
     {\frac{\D^{#1}#2}{\D #3^{#1}}}
\[
\dnbyd{y}{x},\quad \dnbyd{x}{t},
    \quad \dnbyd[n]{y}{x}
\]
\[
    \dnbyd[n]{~}{t} \E^{\I\omega t}
         = (\I\omega)^n\E^{\I\omega t}
\]
```

$$\frac{\mathrm{d}y}{\mathrm{d}x},\quad \frac{\mathrm{d}x}{\mathrm{d}t},\quad \frac{\mathrm{d}^n y}{\mathrm{d}x^n}$$
$$\frac{\mathrm{d}^n}{\mathrm{d}t^n}\mathrm{e}^{\mathrm{i}\omega t} = (\mathrm{i}\omega)^n \mathrm{e}^{\mathrm{i}\omega t}$$

Notice the unbreakable space ~ in the last equation, which ensures that the d's are aligned.

It is good practice either to collect all `\newcommand` definitions together in the preamble at the start of the document, or to put them in a separate file that can be read in with the `\input` command described in §5.2.

An error will result if you inadvertently set up a `\newcommand` with the name of an existing LaTeX command, or one that you have already used. A command may be given a new definition using `\renewcommand` (see page 54 for an example of its use), whose syntax is the same as `\newcommand`. Care must be exercised not to accidentally redefine a built-in system command, since this can have unforeseen consequences.

3.7 Theorem-like Environments

Mathematical documents often contain structures like lemmas, theorems, assumptions, results, and so on. The `\newtheorem` command allows you to define appropriate environments—this ensures that the formatting is consistent and that the numbering and cross-referencing is automated.

For example, suppose we include the line

```
\newtheorem{thm}{Theorem}
```

(as with `\newcommand`, this is best put in the preamble or in a separate customization file). This defines an environment called `thm`, specified by the first argument, which produces structures with the heading Theorem, stipulated by the second argument.

```
\begin{thm}[Anon.]\label{means}
  Let $A = (x+y)/2$,
  $G = \sqrt{xy}$ and
  $H = 2xy/(x+y)$ denote the
  \emph{arithmetic, geometric}
  and \emph{harmonic} means
  of the two positive numbers
  $x$ and $y$. Then
  \[
    A\ge G\ge H.
  \]
\end{thm}
\noindent
\textbf{Proof} ....
```

Theorem 1 (Anon.) *Let* $A = (x + y)/2$, $G = \sqrt{xy}$ *and* $H = 2xy/(x + y)$ *denote the* arithmetic, geometric *and* harmonic *means of the two positive numbers* x *and* y. *Then*

$$A \ge G \ge H.$$

Proof ....

An optional argument in square braces, such as `Anon.` in the above example, allows attribution or other remarks to be added. The key may be used for cross-referencing, as in `Theorem~\ref{means}`.

It is possible to make the numbering scheme operate relative to the section or chapter numbers, and also to make different theorem-like environments share the same numbering scheme. An example of the latter is given by the definition

```
\newtheorem{princ}[thm]{Principle}
```

in which the optional argument `thm` specifies that `princ` structures should share the same numbering scheme as `thm`. For example,

```
\begin{princ}\label{keyprinc}
  The average number of
  arbitrary constants per page
  should not exceed $3.57$.
\end{princ}
```

Principle 2 *The average number of arbitrary constants per page should not exceed* 3.57.

Changing the optional argument `thm` to `section` would produce a heading where, for example, 7.1 signifies the first Principle of section 7. See [8, §3.4.3] for further details.

3.8 Math Miscellany

3.8.1 Math Styles

The examples on page 20 show that some expressions are formatted in different styles depending on whether they are part of an in-line math expression (known as *text style*) or contained in a displayed equation (known as *display style*). Also available are *script style*, which describes how sub/superscripts are formatted (see page 22 for an example of its use), and *scriptscript style*, which relates to a further level of sub/superscripts.

```
In \emph{display style} we have
\[
  \sum_{j=1}^n j^2 = \frac{1}{6}
    n(n+1)(2n+1),
\]
whereas $\sum_{j=1}^n j=
\frac{1}{2}n(n+1)$
appears in \emph{text style}.
```

In *display style* we have

$$\sum_{j=1}^{n} j^2 = \frac{1}{6}n(n+1)(2n+1),$$

whereas $\sum_{j=1}^{n} j = \frac{1}{2}n(n+1)$ appears in *text style*.

You can insist on formatting of a particular style with one of the declarations

`\displaystyle, \textstyle, \scriptstyle, \scriptscriptstyle`

as illustrated in the next example. Once one of these declarations is invoked, it remains in effect until the end of the current math mode unless it, and the expression to be affected, are enclosed in curly braces. These rules are similar to those that apply to `\large`, `\huge`, etc., described on page 8. (Note that `\large`, `\huge`, and the other size-changing commands apply only to text mode and are ignored in math mode.)

```
Overriding the default
styles gives
\[
  \textstyle\sum_{j=1}^n j^2 =
   \frac{1}{6} n(n+1)(2n+1),
\]
and ${\displaystyle\sum_{j=1}^n} j
  = \frac{1}{2}n(n+1)$.
```

Overriding the default styles gives

$$\textstyle\sum_{j=1}^{n} j^2 = \frac{1}{6}n(n+1)(2n+1),$$

and $\displaystyle\sum_{j=1}^{n} j = \frac{1}{2}n(n+1)$.

The scope of `\displaystyle` in the previous example was restricted to the summation symbol.

The commands `\tfrac{.}{.}` and `\dfrac{.}{.}` from the `amsmath` package produce text style and display style fractions, respectively, regardless of the context.

```
\[
 u_j = \frac{1}{4}
       \sin^2 \tfrac{1}{2} \pi jh
\]
while
\[
 v_j = \tfrac{3}{4}
       \cos^2\frac{1}{2}\pi jh
\]
and $u_j/v_j=\dfrac{1}{3}\tan^2 \frac{1}{2}\pi jh$.
```

$$u_j = \frac{1}{4}\sin^2 \tfrac{1}{2}\pi jh$$

while

$$v_j = \tfrac{3}{4}\cos^2 \frac{1}{2}\pi jh$$

and $u_j/v_j = \dfrac{1}{3}\tan^2 \tfrac{1}{2}\pi jh$.

The use of `\frac` should generally be avoided with in-line expressions; $w = (z+1)/(z-1)$, produced with `$w=(z+1)/(z-1)$`, is rather more elegant than $w = \frac{z+1}{z-1}$, produced with `$w=\frac{z+1}{z-1}$`.

3.8.2 Further Math Symbols

The command `\mathbf{...}` introduced on page 25 can be used in math mode to obtain bold letters, numbers, and uppercase Greek letters. Other symbols, such as $=$ and $\geq$, or entire formulas, may be set in bold font with `\boldmath`. This is a declaration that must *not* be used in math mode. Letters are set in bold italic font. Both the commands

```
{\boldmath $a\times b = c$}
```

and

```
\boldmath $a\times b = c$ \unboldmath
```

give $\boldsymbol{a \times b = c}$, which should be compared with $\mathbf{a \times b = c}$ produced by

```
$\mathbf{a\times b = c}$.
```

The `bm` package defines the command `\bm`, which offers a more convenient way of mixing bold, italic, and standard versions of math symbols and characters. So, with the command `\usepackage{bm}` in the preamble, we can produce

```
The Navier-Stokes equations are
\[
  \bm{u\cdot\nabla u}=\bm{\nabla}p
   +\frac{1}{R_e}\nabla^2\bm{u},
\]
where $R_e$ is the Reynolds number.
```

The Navier-Stokes equations are

$$\boldsymbol{u \cdot \nabla u} = \boldsymbol{\nabla} p + \frac{1}{R_e}\nabla^2 \boldsymbol{u},$$

where R_e is the Reynolds number.

Observe that `\mathbf` uses a bold upright font, while `\boldmath` and `\bm` employ an italic font.

Characters typeset in "blackboard" font, such as the symbol $\mathbb{R}$ for the real numbers, are not available in standard LaTeX. The solution is to use symbols from the $\mathcal{AMS}$ package, which requires the command

```
\usepackage{amsfonts}
```

in the preamble. Then `$\mathbb{CNQRZ}$` gives $\mathbb{CNQRZ}$. The command `\mathbb`, like `\mathcal`, provides only uppercase letters and must be used in math mode.

```
For
$\bm{x},\bm{y}\in\mathbb{R}^n$,
we define
\[
  \langle \bm{x}, \bm{y} \rangle =
     \sum_{j=1}^n x_j y_j.
\]
```

For $\boldsymbol{x}, \boldsymbol{y} \in \mathbb{R}^n$, we define

$$\langle \boldsymbol{x}, \boldsymbol{y} \rangle = \sum_{j=1}^{n} x_j y_j.$$

Notice that the `\langle...\rangle` delimiters are used to produce the angled brackets (see Table 3.4).

While the binomial coefficient can be typeset with the `\choose` command—a throwback to earlier versions of TEX—the preferred command is `\binom{.}{.}`, which becomes available when the package `amsmath` is loaded. Both versions are illustrated in the following example.

```
The $n$th Bernstein
polynomial of the function
$f\in C[0,1]$ is defined by
\[
  B_n(x) = \sum_{i=0}^n
   {n \choose i}
    f\big(\frac{i}{n}\big)
    x^i(1-x)^{n-i},
\]
where
\[
 \binom{n}{i} = \frac{n!}{i!(n-i)!}.
\]
```

The nth Bernstein polynomial of the function $f \in C[0,1]$ is defined by

$$B_n(x) = \sum_{i=0}^{n} \binom{n}{i} f\big(\frac{i}{n}\big) x^i (1-x)^{n-i},$$

where

$$\binom{n}{i} = \frac{n!}{i!(n-i)!}.$$

Attention should be drawn to the curly braces in `{n \choose i}` that serve to delimit the scope of the two arguments of the function.

Occasionally, we need to modify or extend the behavior of mathematical operators such as the summation operator ($\sum$). The `\substack` command allows multiline sub- and superscripts. For example, (assuming that the `amsmath` package has been loaded),

```
\[
\pi^4 = 96 \sum_{
  \substack{ n=1\\
     \text{$n$ odd}}}^{\infty}
     \frac{1}{n^4}
\]
```

$$\pi^4 = 96 \sum_{\substack{n=1\\ n \text{ odd}}}^{\infty} \frac{1}{n^4}$$

It is important to use the `amsmath` command `\text` (rather than `\mbox`) in `\substack` since it adopts the appropriate font size when used in sub/superscripts. For illustration, we return to the example involving `\underbrace` and `\overbrace` on page 26.

```
$x^{m}=y^{n}$ means that
\[
\underbrace{x\cdot x\cdots x}%
  _{\mbox{$m$ times}} =
\overbrace{y\cdot y\cdots y}%
  ^{\text{$n$ times}}.
\]
```

$x^m = y^n$ means that

$$\underbrace{x \cdot x \cdots x}_{m \text{ times}} = \overbrace{y \cdot y \cdots y}^{n \text{ times}}.$$

Ornamentation can be applied to the four corners of any mathematical operator that accepts sub- and superscripts using `\sideset`. For example, the command `\sideset{_a^b}{_c^d}\prod` produces ${}_a^b\prod_c^d$. The following example shows a situation that cannot easily be typeset in any other manner.

```
The trapezoidal rule is
defined  by
\[
\int_0^1 f(x)\, \D x \approx
\frac{1}{N}
\sideset{}{''}\sum_{n=0}^N
 f\Big(\frac{n}{N}\Big),
\]
where the double prime on the
summation symbol signifies that
the first and last terms should
be halved.
```

The trapezoidal rule is defined by

$$\int_0^1 f(x)\,\mathrm{d}x \approx \frac{1}{N}\sum_{n=0}^{N}{}'' f\Big(\frac{n}{N}\Big),$$

where the double prime on the summation symbol signifies that the first and last terms should be halved.

(The command \D is defined on page 32.)

The amsmath package provides the commands \iint, \iiint, and \iiiint to format multiple integral signs without having to adjust the spacing as discussed on page 19.

```
\begin{multline*}
  \iiint
   f(r,z)\,\D r\,\D z\,\D\theta\\
    = 2\pi\iint f(r,z)\,\D r\,\D z.
\end{multline*}
```

$$\iiint f(r,z)\,\mathrm{d}r\,\mathrm{d}z\,\mathrm{d}\theta = 2\pi \iint f(r,z)\,\mathrm{d}r\,\mathrm{d}z.$$

A thin space (\,) is still required before each of the differentials.

Chapter 4

Further Essential LaTeX

4.1 Document Classes and the Overall Structure

The example on page 6 shows a full LaTeX file, which begins with the command

```
\documentclass{article}
```

This command tells LaTeX that the document is to have the `article` class. Other classes that are available include `report`, `book`, `slides` (superseded by `beamer`—see Appendix C), and `letter`. The different classes vary in the range of optional arguments that are available, and also in some of the formatting commands that are predefined. We concentrate in this section on information that applies to the `article` and `report` classes; Appendix C deals with the `beamer` class and Appendix D with the `a0poster` class. The `article` class is designed for relatively short documents, such as journal papers, while `report` is meant for longer works that are broken into chapters.

As an alternative to the standard classes built into LaTeX, you can use any available class that has been appropriately defined in a file with a `cls` extension. Suppose that the file is called `myclass.cls`. Then the opening command `\documentclass{myclass}` can be used. A description of how to set up a new class is beyond the scope of this book; see [9] if you wish to know more.

If you are preparing a long, specialized document, such as a thesis, then you may benefit from a customized document class. If you are fortunate, your institution will already have a class available, complete with documentation and sample files. Many `cls` files that have been written by other LaTeXers are available online.

It is possible to specify optional arguments to the `\documentclass` command inside square braces. For example, the default type size of 10 points can be enlarged to 11 points (around 10% bigger) by specifying

```
\documentclass[11pt]{article}
```

Replacing `11pt` by `12pt` would give a type size of 12 points (20% bigger than the default). Note that 11pt and 12pt are the only available variations on the default size of 10pt.

Another optional argument that we could specify with the `article` class is `twocolumn`, which formats the document with two columns per page. The `a4paper` option expands the page formatting dimensions in a way that is suitable for European A4 paper (8.27 × 11.69 inches). Several optional arguments, separated by commas, can be listed in the square braces, so we could choose

```
\documentclass[12pt,a4paper,twocolumn]{article}
```

Other options include `landscape`, `a5paper`, `b5paper`, and `letterpaper`. The `geometry` package provides a more complete range of paper sizes (see §E.5).

4.2 Titles for Documents

A title page can be generated automatically by specifying the title, authors, affiliations, and date. For example, a simplified version of the title page for this book could be generated by the commands

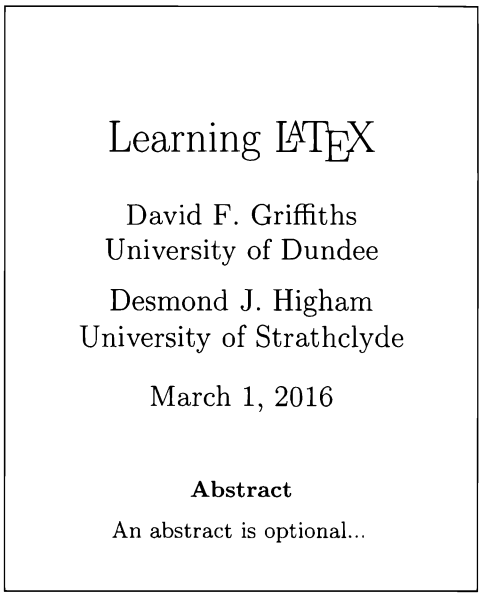
```
\title{Learning \LaTeX}

\author{David F. Griffiths\\
        University of Dundee
        \and
        Desmond J. Higham\\
        University of Strathclyde}

\date{\today}

\maketitle

\begin{abstract}
   An abstract is optional...
\end{abstract}
```



The output corresponds to that from `\documentclass{article}`. Here the `\maketitle` command tells LaTeX to format the title page, using the information supplied by the `\title`, `\author`, and `\date` commands. If there is more than one author, as in the example above, their names are separated by `\and`. An optional `abstract` environment is also available, as shown; this is usually placed immediately after the `\maketitle` command. Further illustration of the use of `\maketitle` with `article` class is given in Appendix A, with `report` class in Appendix B, and with `a0poster` class in Appendix D.

It is possible to add footnotes, for example, to recognize financial support, using the `\thanks` command. Hence, we could replace `David F. Griffiths`

in this example by

```
David F. Griffiths\thanks{Supported by the Bearded Welshman
   Preservation Society.}
```

A `\thanks` footnote can be attached to any word appearing inside the `\title`, `\author`, or `\date`. If the `\date` command is omitted, then the current date is generated. To suppress the date use `\date{}` with an empty argument.

4.3 Sectioning Commands

We can regard LaTeX documents as being organized hierarchically into units such as words, sentences, paragraphs, and sections. The command

```
\section{Introduction}
```

creates a section whose heading is `Introduction`. Each time it encounters the `\section` command, LaTeX starts a new section. The section heading, such as `Introduction`, is specified between curly braces, and the section number is generated automatically. As for displayed equations, we may give the section a key, for example, `intro`, by using

```
\section{Introduction}\label{intro}
```

We can refer to that section later in the document using the `\ref` command.

```
It was shown in Section~\ref{intro} that ...
```

In the preceding example we used the tilde ~ in `Section~\ref{intro}` as a "hard space." It acts as an "unbreakable space" ensuring that there will be the usual spacing between "Section" and the number generated by `\ref{intro}`, but a line break will not be allowed between the two.

The commands `\subsection` and `\subsubsection` further subdivide the document and work in the same way as `\section`. There are also the alternative forms

```
\section*{...},  \subsection*{...},  \subsubsection*{...}
```

which differ from their unstarred counterparts in that they suppress the numbering of the sectional units. With the `report` class, `\chapter` is also available. This is a higher level unit than `\section`; an example is given in Appendix B.

If your document has one appendix or more, then you must insert the command `\appendix`. Having encountered this command, LaTeX treats all subsequent sections (with `article` class) or chapters (with `report` class) as appendices and numbers them accordingly; see Appendix B for an example of the latter.

One of LaTeX's most simple and powerful commands is `\tableofcontents`. This causes LaTeX to produce a table of contents, like the one at the start of

this book, based on the chapter/section/subsection hierarchy in the document. LaTeX stores the information that it needs to produce the table of contents in a file with the `toc` extension. Each time you run LaTeX on the `tex` file, the information in the `toc` file is updated. (After a significant change to the `tex` file, it is necessary to run LaTeX more than once to get the correct table of contents.) The analogous commands `\listoftables` and `\listoffigures` work in the same way, producing files with extensions `lot` and `lof`, respectively.

Returning to `example.tex` on page 6, you will see that the text is contained in the `document` environment. This pattern must always be followed—the main part of the file appears between `\begin{document}` and `\end{document}`. Certain commands, such as `\newcommand` (page 31), are allowed to appear in the preamble; that is, between `\documentclass` and `\begin{document}`. Some commands, such as `\usepackage` (page 51) and `\makeindex` (page 63), must *only* appear in the preamble.

Figure 4.1 shows the typical structure of a document of class `article`. Only the commands `\documentclass`, `\begin{document}`, and `\end{document}` are compulsory. In particular, the commands producing the table of contents and the index (see §5.5) are usually not required for short documents. We also mention that rather than having the entire document in a single `tex` file, it is often more convenient to develop units such as sections or subsections in separate files and to call them up from a "root" file using the `\input` command; see §5.2.

4.4 Miscellaneous Extras

In this section we describe some miscellaneous details that are worthy of note.

4.4.1 Spacing

LaTeX attempts to follow the accepted practice of adding extra space after a period (full stop) that ends a sentence. Any period that immediately follows a lowercase letter and is followed by the blank space character is interpreted by LaTeX as marking the end of a sentence. On the occasions where this interpretation is incorrect, it is good practice to override the default. A backslash followed by the space character forces a normal interword space.

```
Avoid unecessary examples,
e.g.\ this one.

Incomplete lists etc.\
are signs of lazy writing.
```

Avoid unecessary examples, e.g. this one.
Incomplete lists etc. are signs of lazy writing.

Figure 4.1: The structure of a document with `article` class. Only the highlighted lines are essential. Note that several packages may be loaded by a single `\usepackage` command by supplying a comma-separated list as its argument.

In a similar vein, to obtain the correct spacing after a sentence that ends with an uppercase letter, the \@ command is needed.

```
Capitalizing for emphasis is
UGLY and DISTRACTING\@.
Another cheap gimmick
is.....suspense.
```

Capitalizing for emphasis is UGLY and DISTRACTING. Another cheap gimmick is.....suspense.

Difficulties with spacing can also arise when commands are used to produce text. For example, the command \LaTeX produces the logo LaTeX. Blank spaces after the string \LaTeX have no effect on the output—an interword space must be added where necessary.

```
Many \LaTeX\ users'
punctuate incorrectly;
other \LaTeX ers are more
punctilious.

In your quest for
knowledge about \LaTeX ,
stop at nothing.
```

Many LaTeX users' punctuate incorrectly; other LaTeXers are more punctilious.
In your quest for knowledge about LaTeX, stop at nothing.

An interword space was included after \LaTeX on the first line while \LaTeX and ers merged to form "LaTeXers." In the second sentence, we could use \LaTeX, instead of \LaTeX , (the comma cannot be part of a command name and hence it signals that the command has ended).

4.4.2 Accented Characters

Table 4.1 lists some commands that produce accented characters and other symbols.

```
We can therefore properly set
the names of the well-known
Scandinavian numerical analysts
{\AA}ke Bj\"{o}rck from Sweden
and S.~P.~N{\o}rsett from
N{\o}rway!
```

We can therefore properly set the names of the well-known Scandinavian numerical analysts Åke Björck from Sweden and S. P. Nørsett from Nørway!

Table 4.1: Accents and other symbols.

\`{a}	à	\'{e}	é	\"{u}	ü	\H{o}	ő	\.{u}	ṷ
\^{o}	ô	\v{c}	č	\u{o}	ŏ	\c{c}	ç	\d{s}	ṣ
\~{n}	ñ	\t{oo}	o͡o	\={c}	c̄	\b{c}	c̲	\OE	Œ
\AA	Å	\aa	å	\AE	Æ	\ae	æ	\oe	œ
\ss	ß	\O	Ø	\o	ø	\L	Ł	\l	ł
\S	§	\P	¶	?`	¿	!`	¡	\#	#
\dag	†	\ddag	‡	\%	%	\&	&	_	_
\copyright	©	\pounds	£	\$	$	\{	{	\}	}

Recall from page 41 that each ~ in `S.~P.~N{\o}rsett` is an "unbreakable space" that prevents a line break. This ensures that the spacing between the initials and surname will remain, but the whole name, initials+surname, will be treated as one word and not broken across a line boundary.

4.4.3 Dashes and Hyphens

Care must be taken to distinguish between the three types of hyphen that connect words, specify a range, and punctuate; these are produced with -, --, and ---, and give -, –, and —, respectively. (In some circumstances typesetting convention dictates that the -- hyphen should also be used to connect words [5, page 153].) The math minus (− produced by $-$) is yet another type of dash.

```
\begin{enumerate}
\item Introduce meaningless
jargon on a strict
need-to-know basis.

\item Never reveal your sources
(\emph{Alistair Watson},
The Autobiography,
pages 22--23.)

\item Sarcasm---yes, I bet that
will go down really well.
\end{enumerate}
```

1. Introduce meaningless jargon on a strict need-to-know basis.
2. Never reveal your sources (*Alistair Watson*, The Autobiography, pages 22–23.)
3. Sarcasm—yes, I bet that will go down really well.

4.4.4 Quotation Marks

The double quotes character " is rarely used in LaTeX documents. Left and right double quotes should be produced with pairs of single quotation marks.

```
\begin{description}
\item[Wrong:] My old high school
  English teacher put it
  perfectly when she said:
 "Quoting is lazy. Express things
  in your own words."
\item[Right:] She also said:
 ``Don't use that trick of
   paraphrasing.....[other
   people's words].....inside
   a quote.''
\end{description}
```

Wrong: My old high school English teacher put it perfectly when she said: "Quoting is lazy. Express things in your own words."

Right: She also said: "Don't use that trick of paraphrasing.....[other people's words].....inside a quote."

4.5 Troubleshooting

When you run LaTeX, processing might come to a premature end with a message that looks like

```
! LaTeX Error: \begin{itemize} on input line 26 ended by \end{document}.

See the LaTeX manual or LaTeX Companion for explanation.
Type  H <return>  for immediate help.
 ...

l.133 \end{document}

?
```

This is an error message—it tells you that LaTeX thinks there is a mistake in your file. In this case the environment opened on line 26 of the `tex` file has not been closed. (If you are processing several files by means of the `\input` command, then the line number relates to the last file to be used—file names are displayed on the screen as they are included.)

After displaying an error message, the `?` signifies that LaTeX is waiting for a response from you. Hitting the Return (or Enter) key tells LaTeX to continue processing, typing `x` followed by Return causes LaTeX to stop, and typing `h` followed by Return produces a helpful message about the nature of the error. For the sake of efficiency, it is a good policy to hit Return by default—you may need to do this several times. Once the processing is finished, after taking note of the error messages you can make the appropriate edits to the `tex` file. Sometimes, however, an error has so many consequences that it is necessary either to suppress further error messages with `q` (to run quietly) or to stop the processing with `x`. In such cases effort should be focused on fixing the *first* error, since this may well have had a "knock-on" effect. A list that includes other responses is given in Table 4.2.

In addition to displaying information on the screen, LaTeX produces a log file; this usually has the `log` extension. The log file contains all the error

Table 4.2: Your options when LaTeX gives an error message.

Response by you	Action from LaTeX
Return (or Enter)	Continue processing.
`?`	Type a list of possible actions.
`h`	Give a slightly more helpful error message.
`r`	Run without stopping; subsequent error messages are reported but no further action is required from the user. This is likely to generate substantial output from LaTeX.
`q`	Run quietly; no further error messages will be issued.
`x`	Stop.
`e`	Edit file; the default editor is summoned and the cursor placed at the reported location of the error.

and warning messages, as well as other information, so it may be worthwhile loading the log file into your editor to inspect its contents more closely.

4.5.1 Pinpointing the Error

Although information is provided by the error message and the `help` facility, there are occasions when an error is difficult to track down. There are several techniques for pinpointing an error.

- Some text editors will automatically jump to the reported location of the error.

- If a `pdf` or `dvi` file has been produced, then preview or print the output. This may make the error apparent.

- Insert the `\end{document}` command before the line on which the error was detected and run LaTeX on this abbreviated document to check that it is processed without error.

  Now move `\end{document}` a little further down the document and run LaTeX again. Repeat this procedure until the error is reported. This allows you to narrow down the suspect text.

- Copy the file to `junk.tex`. Repeatedly delete text from `junk.tex` and run LaTeX until you have the smallest possible file that reproduces the error. By this stage the error should be apparent.

4.5.2 Common Errors

The following are among the most common errors.

- Unsymmetric delimiters; for example a `{` without a matching `}`, a `\begin` without the corresponding `\end`, or in-line mathematics without a matching pair of `$`'s. These produce error messages of the type

```
! Paragraph ended before \ref was complete.
<to be read again>
                   \par
l.51
?
```

  caused by `\ref{key` (no closing brace), or

```
! Missing $ inserted.
<inserted text>
                $
l.56
?
```

  caused by nonmatching `$`'s.

- Mistyped commands, for example, `\begin{centre}` rather than `\begin{center}` or `multiline` rather than `multline`.

- Mathematical commands, such as `\sin` or `x_n`, in a nonmathematical environment.

- A blank line in an equation environment.

- A missing space or other delimiter after a command. For example, typing `\sinx` rather than `\sin x` will cause an error since the command `\sinx` is not recognized.

- An "ordinary" occurrence of one of the special characters (`%, $, #`, etc.) without a preceding `\` (see page 7).

- Double subscripts or superscripts; for example, the ambiguous `$x_n_i$` rather than `${x_n}_i$`, which produces x_{ni}, or `$x_{n_i}$`, which produces x_{n_i}.

If LaTeX stops processing with a `*`, this may be due to a missing `\end{document}` and you should respond with `\stop`.

In order to make it easier to deal with errors, it is good practice to run LaTeX on various intermediate versions of a document as it builds up. In this way you should avoid having a large number of errors that propagate through the document. Alternatively, by exploiting the `\input` command (see §5.2), you can run LaTeX on different parts of the document before putting it all together.

4.5.3 Warning Messages

Messages that begin with the ! sign denote errors, and these have to be fixed before the entire document can be properly processed. LaTeX also gives out warning messages, such as

```
Overfull \hbox (3.07341pt too wide) in paragraph at lines 342--342
```

In this case the warning relates to an overfull `\hbox`—a good place to break line 342 (of the `tex` file) could not be found and so the output will extend beyond the right margin; an instance of this has been deliberately included below. Warnings such as these are probably best ignored until the "final" version of the document is ready, after which it may be necessary to insert `\linebreak` or `\pagebreak` commands which force line breaks and page breaks, respectively.

Some common warning messages related to labeling and cross-referencing are exemplified by

`LaTeX Warning: Label 'eq:pde' multiply defined.`

The key `eq:pde` was defined more than once in the same document.

`LaTeX Warning: Citation 'Lampurt' on page 3 undefined on input line 184.`

A bibliography entry corresponding to the key in a `\cite` was not found. You may have mistyped the key or forgotten to include the entry in `thebibliography` (see §5.4).

`LaTeX Warning: Reference 'eqn' on page 3 undefined on input line 178.`

The key `eqn` in a `\ref` was not found. You may have mistyped the key or forgotten to include a definition using `\label` (see page 13).

`LaTeX Warning: There were undefined references.`

`LaTeX Warning: There were multiply-defined labels.`

These are both printed at the conclusion of processing in case you missed the earlier warnings.

`LaTeX Warning: Label(s) may have changed.`
`Rerun to get cross-references right.`

This warning appears when you add to or alter the information that determines cross-references for equations, tables, sections, etc. LaTeX handles cross-referencing with a two-pass algorithm; consequently you must run LaTeX twice (sometimes three times) in order for information to be updated. (If you omit the extra run, then you face the possibility of incorrect cross-references.)

If, even after following the tips above, you have trouble locating an error or understanding a message, then the information in Chapter 8 of [8] may prove useful.

Chapter 5

More About LaTeX

5.1 Packages

The basic capabilities of LaTeX can be greatly enhanced by the use of *packages*. A package, which takes the form of a file with a `sty` extension, can be used to alter formatting parameters, create new environments, and define (or redefine) commands. Many packages are available, covering tasks such as producing special boxes, formatting computer programs, and generating obscure mathematical symbols, in addition to adding extra features to commands like `\verbatim` and `\cite`.

The book [9] details several hundred packages, many of which come bundled with the standard LaTeX distribution. A comprehensive list of packages is provided by *The TeX Catalogue Online*; details of how to acquire this catalogue (along with the packages and their accompanying documentation) are given in Appendix E. It is possible to write your own packages, but, whatever your requirements, it is likely that something suitable already exists.

The packages `amsmath` (pages 24, 27–31), `amsfonts` (page 36), `bm` (page 36), `epstopdf` (page 52), `geometry` (pages 40, 89), `graphicx` (page 52), and `makeidx` (pages 43, 63) are among those mentioned elsewhere in this book. The command `\usepackage`, which may only appear in the preamble, tells LaTeX to load a package. Options are included in square braces.

5.2 Inputting Files

It is often natural and convenient to prepare a document as a collection of separate files. This can be done by creating a "root" file, say `main.tex`, in which the `\input` command is used. Suppose `main.tex` contains the command `\input{section1}`. Then when LaTeX is run on `main.tex`, the output produced (in `main.pdf`) is identical to that which would have arisen if `\input{section1}` had been replaced by the contents of the file `section1.tex`. In other words, LaTeX reads in the file at the appropriate point. See Appendix D for examples of its use.

This facility is useful for several reasons. First, it lets you work with relatively small files, which are easier to edit. Second, it allows you to speed up the debugging phase by selectively including certain parts of a large document. Third, it gives you the chance to set up a collection of frequently arising `\newcommand` declarations (see §3.6) that can be used for future documents. Note, however, that when submitting an article for publication, you may be required to provide a single `tex` file.

5.3 Inputting Pictures

You may wish to display pictures, such as function plots or digitized photographs, that have been generated by some other computer package. This can usually be done with the `\includegraphics` command.

If the document is processed by LaTeX to produce a `dvi` file, then the graphical files should be in encapsulated PostScript (`eps`) format. The `dvips` program can then be used to convert the `dvi` to PostScript for display or printing. A wider range of graphic formats (`png`, `pdf`, `jpg`, and `eps`) can be accommodated by processing the document with `pdflatex`, which has the added convenience of producing a `pdf` file directly.

Whichever processing approach is adopted, the `graphicx` package must first be loaded by including the command

```
\usepackage{graphicx}
```

in the preamble. With some installations of LaTeX it may also be necessary to load the `epstopdf` package (see §E.5) if `eps` files are to be used with `pdflatex`.

The command `\includegraphics{pic}` will then cause LaTeX to search the current folder for a graphics file `pic` with a suitable extension. If the figure is available in several different formats, it will search for `pic.png`, `pic.pdf`, `pic.jpg`, or `pic.eps` (which will be converted—and saved—to `pdf` format) in that order. If a suitable file is found, then the figure will appear in the document in its natural size. Otherwise an error message will be displayed saying that the requested file cannot be found. Including the command

```
\graphicspath{ {figures/} }
```

in the preamble will cause LaTeX to also search the folder `figures`, relative to the current folder, for graphics files.

The size and orientation of the image can be controlled by including options to the `\includegraphics` command. For example, the width of the picture can be set to 50% of the line width in the current environment with the command

```
\includegraphics[width=0.5\linewidth]{pic}
```

By changing the option to `[width=50mm]`, for example, it can be set to an absolute value. Both options respect the original aspect ratio of the image. The height of the image may be set in a similar way. If both the width and

height are specified, then the aspect ratio will generally be changed. The image can be rotated through 45°, say, by adding the option `angle=45`.

It is common to present a picture as a figure, so that it can be captioned, labeled, and referenced. This can be done with the `figure` environment, which creates a floating body in the same way as the `table` environment discussed on page 11. The following LaTeX commands produce Figure 5.1.

```
\begin{figure}
    \centering
    \includegraphics[width=.9\linewidth]{pic}
    \caption{Stages in building a Koch snowflake.}
    \label{koch-fig}
\end{figure}
```

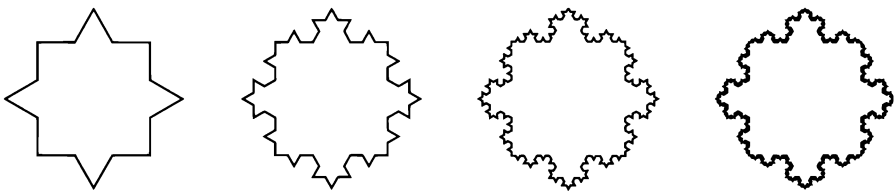


Figure 5.1: Stages in building a Koch snowflake.

The graphical image in the figure has been centered with the command `\centering`, which differs from the center environment used on page 11 in that it introduces less vertical space. An image may also be trimmed (or cropped). For example, in the command

```
\includegraphics%
      [trim={40mm 0mm 80mm 0mm},clip=true,width=5mm]{pic}
```

the four lengths given to `trim` set the amounts to be trimmed from the left, bottom, right, and top of the image, respectively. The trim is enforced by `clip=true` and the result scaled to have width 5mm. When this is applied to the image in Figure 5.1 it isolates the second snowflake from the left and shrinks it to give  . The alternative command

```
\includegraphics%
      [width=1em,viewport=0 0 32mm 30mm,clip=true]{pic}
```

selects the leftmost snowflake. The rectangle to be displayed is defined by the four lengths given to `viewport`. These specify the coordinates of its lower left corner, `0 0`, and its upper right corner, `32mm 30mm`. The result is  when shrunk to a width of `1em` (i.e., the width of M). Determining the precise coordinates is a matter of experimentation, which is facilitated by drawing a box around the object with the commands

```
\setlength{\fboxsep}{0pt}
\fbox{\includegraphics[...]{...}}
```

The first of these sets the distance between the box frame and its contents to `0pt` (so that it fits snugly) and the appropriate arguments in the second command give ⬚.

Further details can be found in [1, 8, 9] or in `grfguide.pdf` listed in §E.5.

5.4 Making a Bibliography

We begin by describing a manual approach to the creation of a bibliography with the `thebibliography` environment. This is similar to the list-making environments discussed in §2.3.1. The command `\bibitem`, whose argument is enclosed in curly braces, precedes each entry. The argument specifies the key by which the entry can be cited, anywhere in the document, using the `\cite` command.

The example on page 55 shows that more than one key can be given to the `\cite` command. Multiple keys must be separated by commas (but not by spaces). The example also illustrates the use of the optional extra argument for `\cite`. If text is enclosed in square braces before the main argument (which is enclosed in curly braces), then this text is added to the citation. Note the second argument "`{99}`" in

```
\begin{thebibliography}{99}.
```

This is required to give LaTeX an upper limit on the width of the labels appearing in the bibliography list. In our example the labels are 1, 2, 3, and 4, none of which are wider than "99". If the number of entries was between 100 and 999, then we could use `\begin{thebibliography}{999}`.

With the `documentclass book` or `report` the results (see pages 55, 73, and 91) appear as an unnumbered chapter with the title "Bibliography." In articles they appear as an unnumbered section with the heading "References" (see page 69). These names can be changed with the respective commands

```
\renewcommand{\bibname}{Reading List}
\renewcommand{\refname}{Publications}
```

for instance.

It is possible to override the numerical labeling, 1, 2, ..., by including the optional extra argument of `\bibitem`. This optional argument is enclosed in square braces before the main argument, and it is used by LaTeX for the label.

```
\begin{thebibliography}{xxxxxx}
\bibitem[Alph48]{ABG}
  Alpher, R.~A., Bethe, H. and
          Gamow, G.,
  \emph{The origin of chemical
        elements},
  Physical Review, \textbf{73}, 1948, 803--804.
\end{thebibliography}
```

> [Alph48] Alpher, R. A., Bethe, H. and Gamow, G., *The origin of chemical elements*, Physical Review, **73**, 1948, 803–804.

The citation `\cite{ABG}` produces "[Alph48]."

```
The \texttt{thebibliography}
environment appears below.
We can refer to items by their
keys. For example, I have read
\cite{Bryson,Schwartz}
and I am currently reading
\cite[page~134]{Leunen}.
Most of the words in
\cite{Bryson,Leunen,Schwartz}
can be found, in a different
order, in \cite{OED}.

\begin{thebibliography}{99}

\bibitem{Bryson}
  Bill Bryson,
  \emph{Bryson's Dictionary
  of Troublesome Words},
  Reprint edition, Broadway Books,
  2004. ISBN 0-7679-1043-5

\bibitem{Leunen}
  Marie-Claire van Leunen,
  \emph{A Handbook for Scholars},
  revised ed. (First edition Knopf,
  1978), Oxford University
  Press, New York, 1992.
  ISBN 0-19-506954-4.

\bibitem{OED}
   Oxford University Press,
   \emph{The Oxford English
   Dictionary}, Seventh ed., 2012.
   ISBN 0-19-964094-7

\bibitem{Schwartz}
   David Louis Schwartz,
   \emph{How to be a published
   mathematician without trying
   harder than necessary}, in
   The Journal of Irreproducible
   Results: Selected Papers,
   third ed., George H. Scherr,
   ed., 1986, p.~205.

\end{thebibliography}
```

The thebibliography environment appears below. We can refer to items by their keys. For example, I have read [1, 4] and I am currently reading [2, page 134]. Most of the words in [1, 2, 4] can be found, in a different order, in [3].

Bibliography

[1] Bill Bryson, *Bryson's Dictionary of Troublesome Words*, Reprint edition, Broadway Books, 2004. ISBN 0-7679-1043-5

[2] Marie-Claire van Leunen, *A Handbook for Scholars*, revised ed. (First edition Knopf, 1978), Oxford University Press, New York, 1992. ISBN 0-19-506954-4.

[3] Oxford University Press, *The Oxford English Dictionary*, Seventh ed., 2012. ISBN 0-19-964094-7

[4] David Louis Schwartz, *How to be a published mathematician without trying harder than necessary*, in The Journal of Irreproducible Results: Selected Papers, third ed., George H. Scherr, ed., 1986, p. 205.

This approach of constructing a thebibliography environment is fine for short, one-off documents. However, if it is likely that over the course of a few years you will write several substantial LaTeX documents with similar bibliographies, then we strongly recommend using the BibTeX program described in the next subsection.

5.4.1 BibTeX

BibTeX is a stand-alone program that comes bundled with the standard LaTeX distribution. It builds a `bbl` file from entries held in one (or more) databases. It offers several advantages over the direct use of `thebibliography`.

- References need only be entered into a database once, after which the details can be reused for any number of documents. Similarly, only a single master entry is maintained for each reference. So, if you are preparing several documents that cite a common reference, then any update—for example, a technical report being superseded by a published article—only requires a single edit.
- BibTeX gives you immediate access to a wide range of referencing styles, covering the requirements of most journals, publishers, and institutions.
- BibTeX entries are easy to share with your colleagues, and many publishers, repositories, and authors offer BibTeX database entries that may be downloaded directly.
- By making BibTeX entries for documents available online, you can encourage others to cite your work. Moreover, by preparing the BibTeX entries yourself, you can promote the accurate citation of your work. This is particularly relevant when names or titles contain accents or mathematical symbols.

To illustrate the way LaTeX and BibTeX combine, we suppose that our main file is `first.tex`. When this is processed by the commands

`pdflatex first` or `latex first`

an auxiliary file `first.aux` is generated as described in §1.3. This file contains a record of all the citations (made through `\cite` commands), the name(s) of the file(s) holding the bibliographic information (`bib` file(s)), and a means of identifying the style in which the bibliographic items are to be formatted (the name of a `bst` file). Now the command

`bibtex first`

reads the information in the `aux` file, extracts the requested items from the database(s), formats them according to the instructions in the `bst` file, and outputs the results to the file `first.bbl`. The overall process is illustrated in Figure 5.2.

The next run of the command `pdflatex` (or `latex`) reads in and typesets the contents of the `bbl` file but it cannot, at this stage, resolve the citations that occur before the bibliography in the document, so the `pdflatex` command has to be run once more. To summarize, the sequence of commands is

`pdflatex, bibtex, pdflatex` (twice).

This sequence has to be repeated each time new citations are added or the `bib` database is modified.

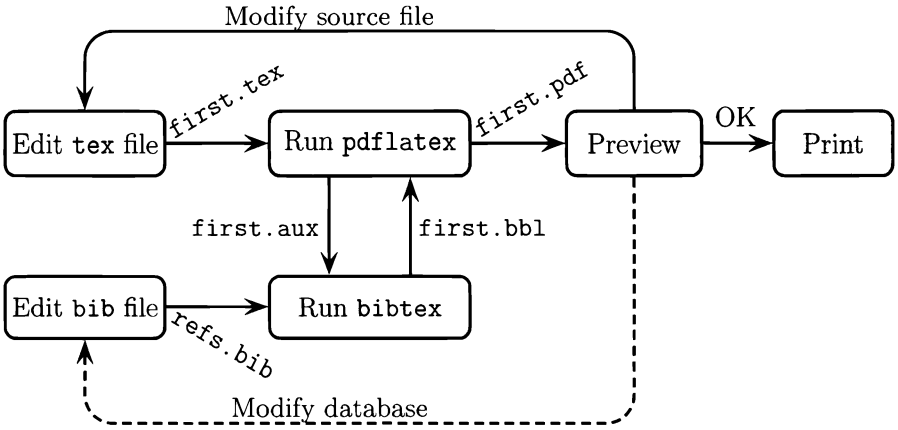


Figure 5.2: The process of generating a `pdf` document from a `tex` file that extracts its bibliography from a `bib` file. Note the exchange of information between `pdflatex` and `bibtex`.

We now turn our attention to the specifics of using BibTeX. The `tex` file has to be primed to place the appropriate information in the `aux` file. This is accomplished by two commands, `\bibliographystyle` and `\bibliography`. The first of these has one argument for which there are four built-in values

`plain`, `unsrt`, `abbrv`, and `alpha`

These refer to the names of `bst` files that are part of the standard LaTeX distribution. The first three produce numbered items, while `alpha` produces alphanumeric labels of the type shown in the example on page 54. The `unsrt` style lists the bibliographic entries in the order they are cited, and the others adopt an alphabetic ordering. The main feature that distinguishes `abbrv` and `plain` (which produces output very similar to that shown on page 55) is that authors' forenames are abbreviated to their initials. This is the style we adopt in the remaining examples so our `tex` file contains the command

```
\bibliographystyle{abbrv}
```

Many more styles can be found on the CTAN website (see §E.1), and most publishers and journals have their own house style, which authors are obliged to adopt. Our publisher uses `siamplain.bst`.

If the database is held in a file `refs.bib`, then the second command required in the `tex` file is

```
\bibliography{refs}
```

which should be located where the bibliography is to appear. If the data is held in more than one `bib` file, then the file names should be separated by commas with no spaces. For example

```
\bibliography{mathrefs,physrefs,chemrefs}
```

We now turn to the structure of the database—the `bib` file. It consists of an entry for each bibliographic item. These may appear in any order. The entry corresponding to the first item on page 55 might look like

```
@book{BB04,
 Author    = {Bill Bryson},
 Title     = {Bryson's Dictionary of Troublesome Words},
 Year      = {2004},
 Publisher = {Broadway Books},
 Note      = {Reprint edition, ISBN 0-7679-1043-5}
}
```

The `@book` specifies the entry type and it has a number of arguments. The first is the citation key, so the book would be referred to in the text as `\cite{BB04}`. The remaining arguments take the form of a comma-separated list of

```
field = value
```

The fields, in the above example `Author`, `Title`, etc., can appear in any order and can be typed in lowercase, uppercase, or (as here) a mixture. Their associated values are enclosed in curly braces. It is also possible to delineate the values using the double quote character, as in

```
Author = "Bill Bryson"
```

It is common practice to enter each field and its corresponding value on separate lines, aligned as shown, to improve readability (to conserve space, we have not always adhered to this noble policy).

There are, of course, many other entry types apart from `@book`. We limit our coverage to a subset. Each type has "required fields," "optional fields," and "ignored fields." Any field that is not recognized as part of the associated type is ignored without any warning being issued. This can make mistyped field names hard to spot. In the following list the fields appearing before the separator || are required, and those appearing after are optional. The order in which they are used is immaterial.

`@article`, author, title, journal, year || volume, number, pages, month, note

`@book`, author or editor, title, publisher, year || address, edition, volume or number, pages, month, note

`@inproceedings`, author, title, booktitle, year || publisher, address, editor, volume or number, series, pages, month, organization, note

`@misc`, *none* || author, title, month, year, howpublished, note

`@phdthesis`, author, title, school, year || type, address, month, note

`@proceedings`, title, year || editor, volume or number, series, address, pages, month, publisher, organization, note

`@techreport`, author, title, institution, year || type, number, address, month, note

Other types that are not covered here are `booklet`, `conference`, `inbook`, `incollection`, `manual`, `mastersthesis`, and `unpublished`.

The following example features three of the most common types.

```
@book{PWZ96,
 Author    = {Marko Petkovsek and
 Herbert Wilf and Doron Zeilberger},
 Title     = {$A=B$},
 Publisher = {A. K. Peters Ltd},
 Address   = {Wellesley, MA},
 Year      = {1996}
}
@article{Eva80,
 Author = {David E. Evans},
 Title  = {{On $O_n$}},
 Journal= {RIMS, Kyoto University},
 Pages  = {915--927},  Volume = {16},  Year = {1980}
}
@phdthesis{Raa01,
 Author = {Mark Aaron van Raamstonk},
 Title  = {Making the Most Out of Zero Branes and a Weak Background},
 School = {Princeton University}, Year = {2001}      }
```

[1] D. E. Evans. On O_n. *RIMS, Kyoto University*, 16:915–927, 1980.

[2] M. Petkovsek, H. Wilf, and D. Zeilberger. $A = B$. A. K. Peters Ltd, Wellesley, MA, 1996.

[3] M. A. van Raamstonk. *Making the Most Out of Zero Branes and a Weak Background.* PhD thesis, Princeton University, 2001.

It can be seen that mathematical expressions may appear in the fields and that multiple authors are separated by "`and`". Also worthy of note are the double curly braces in the title of the article by Evans [1]. They are necessary because only the leading character in an `@article` title will be capitalized unless there is protection from a second level of braces, and the lowercase interpretation of O_n produces an unwanted result. The value could also have been entered as `{On {$O_n$}}`. If the first letter of a word such as Scotland needs to be capitalized, then it could be entered as either `{Scotland}` or `{S}cotland`; we recommend the first of these since it does not interfere with any subsequent searches of the `bib` file. It can be seen in the examples that the same title capitalization rule applies to `@inproceedings` and `@techreport` but not to `@book`, `@phdthesis`, or `@proceedings`.

The `Note` field has been used in Shewchuk [2], shown below, to specify the edition. This is in keeping with the general principle that the names of the entry types are only intended as guides to their contents. The `crossref` field in Dahlquist [1] cross-references the item with Watson [3] and avoids duplication of the information given in Watson. The use of `crossref` requires the additional field `Booktitle` in Watson (so that BibTeX can pass the information to the Dahlquist entry, which requires such a field). Also, the

```
@inproceedings{Dah75,
 crossref= {Wat75},
 Author  = {Germund Dahlquist},
 Title   = {Error Analysis for a
     Class of Methods for Stiff
     Non-linear Initial Value
     Problems},
 pages   = {60--72}
}
@proceedings{Wat75,
 Year      = {1975},
 Editor    = {G. A. Watson},
 Volume    = {506},
 Publisher= {Springer},
 Title     = {Numerical Analysis,
    Dundee},
 Booktitle= {Numerical Analysis, Dundee},
 Series    = {Lecture Notes in Mathematics}
}
@techreport{She94,
 Author = {Jonathan Richard Shewchuk},
 Institution = {Carnegie Mellon University},
 Year    = {1994}, Month = {August}, Note = {Edition $1\frac{1}{4}$},
 Title  = {An Introduction to the Conjugate Gradient Method Without
   the Agonizing Pain}   }
```

[1] G. Dahlquist. Error analysis for a class of methods for stiff non-linear initial value problems. In Watson [3], pages 60–72.

[2] J. R. Shewchuk. An introduction to the conjugate gradient method without the agonizing pain. Technical report, Carnegie Mellon University, August 1994. Edition $1\frac{1}{4}$.

[3] G. A. Watson, editor. *Numerical Analysis, Dundee*, volume 506 of *Lecture Notes in Mathematics*. Springer, 1975.

Watson entry must come after any entries that refer to it. Had Watson not been cited, then the Dahlquist entry would have appeared with more detail.

[1] G. Dahlquist. Error analysis for a class of methods for stiff non-linear initial value problems. In G. A. Watson, editor, *Numerical Analysis, Dundee*, volume 506 of *Lecture Notes in Mathematics*, pages 60–72. Springer, 1975.

The command `\nocite{Wat75}` will extract the corresponding entry from the database, allowing it to be formatted in the bibliography, but not cited. To extract all items use `\nocite{*}`.

A wide range of documents can be located on the Internet by a URL (uniform resource locator), by a DOI (digital object identifier), or from a repository such as `arXiv` (in which the X is pronounced as in LaTeX, so that it sounds like "archive"). We shall use the package `url` to illustrate how these may by included in a bibliography. This package provides the command `\url{...}`, which formats its argument in much the same way as the `\verb` command, except that it includes line breaks for long strings.

As well as the paper version of the journal, the article by Lindner and Strang [2], listed below, is available electronically on `arXiv` (by entering `arXiv:1112.0582` into a search engine), by using the given URL in an Internet browser, or by entering its DOI (10.1016/j.laa.2012.02.034) at the website `https://www.doi.org`. Also, typing the same DOI into the website `http://www.doi2bib.org` will generate a BibTeX entry suitable for inclusion

```
@article{Lin13,
 Title  = {The Main Diagonal of a
   Permutation Matrix},
 Author = {Marko Lindner and
   Gilbert Strang},
 Journal= {Linear Algebra  Appl.},
 Volume = 439,
 Year   = 2013,
 Pages  = {524-537},
 Note   = {\url{arXiv:1112.0582},
   DOI:
   \url{http://dx.doi.org/
   10.1016/j.laa.2012.02.034}}
 }
@misc{Hig15,
 Author  = {Nicholas J. Higham},
 Title   = {{Three \textsc{Bib}\TeX\ Tips}}, Year = 2015, Month = dec,
 howpublished =
   {\url{https://twitter.com/nhigham/status/676764138367033344}}    }
```


[1] N. J. Higham. Three BibTeX Tips. https://twitter.com/nhigham/status/676764138367033344, Dec. 2015.

[2] M. Lindner and G. Strang. The main diagonal of a permutation matrix. *Linear Algebra Appl.*, 439:524–537, 2013. arXiv:1112.0582, DOI: http://dx.doi.org/10.1016/j.laa.2012.02.034.

in a `bib` file. This example illustrates that curly braces are not required to surround a field value that consists of a single integer. A situation in which braces should not be included is illustrated by the value of the `Month` field of the blog by N. J. Higham [1]. This is because we have used the built-in abbreviation `dec` for December (which would require braces), and which is formatted as "Dec." in this bib style.

It is possible to define your own abbreviations. For example, placing

```
@string{sinum = {SIAM J. Numer. Anal.}}
```

in the `bib` file would allow `Journal = sinum` to be used instead of

```
Journal = {SIAM J. Numer. Anal.}
```

Not only does this save on typing, but it also allows the journal name to be typeset consistently throughout the bibliography.

To complete this section we mention the thorny issue of multipart author/editor names. These can cause sorting errors unless they are entered appropriately. Referring to the bibliography example on page 55, names such as "David Louis Schwartz" can be entered either as shown or surname first, as in `Schwartz, David Louis`, without affecting the way the entry appears or its position in an alphabetic list. Had the comic-book character Alan von Neumann Jr. been successful in constructing the ultimate thinking machine, we could enter his name as

```
author = {von Neumann, Jr., Alan}
```

in the resulting publication in order for it to be sorted correctly (BibTeX deals with `von` appropriately). For names that include accented characters, such as that of the eminent numerical analyst Endre Süli, curly braces should be placed around the command that creates the accent, as in

```
author = {Endre S{\"{u}}li}
```

The field `key` is provided for entries that have no `author` field, such as *The Oxford English Dictionary* on page 55. With `key = {The Oxford}` it would be alphabetized under "T."

Our coverage of BibTeX has been necessarily brief. For further information, see the web site `http://www.bibtex.org`, the article by Patashnik (see page 89) and the books [6, Chapter 12] or [9, Chapters 12 & 13].

5.5 Making an Index

If you wish to make an index, like the one at the back of this book, then LaTeX offers some helpful facilities. We assume here that you will use the program *MakeIndex*, which is included with most LaTeX distributions. This program removes a lot of the tedium from index creation. We shall give a number of examples, many of which are taken from different parts of this book. We recommend that you refer to the index in each case to see the effect.

The first step in generating an entry in the index is to insert the `\index` command in the relevant location. For example, the entry for "comments" in the index at the back of this book refers to page 7, and the LaTeX source to generate that part of the page looks like

```
...a mechanism for inserting comments\index{comments} into...
```

The `\index` command has no effect on the text appearing on page 7. However, it causes LaTeX to make a note of the page number, which can then be used for the index entry. To make sure that the correct page number appears in the index we leave no space between the word `comments` and the command `\index{comments}`. (Otherwise, if "comments" happened to be the last word on the page, then the `\index` command would relate to the next page.)

It is important not to add leading spaces inside the index command. If we had used `\index{ comments}` instead of `\index{comments}`, then the entry would have appeared at the start of the index, since LaTeX deems that the leading space comes before "a" in the alphabet.

The `%` character described on page 7 is useful if you want to make your indexing commands stand out in the LaTeX file. In the example above we could have used

```
...a mechanism for inserting
\index{comments}%
comments into...
```

Here, since LaTeX ignores everything that follows `%` on the same line (plus any leading spaces on the next line), there is effectively no space between `\index{comments}` and `comments`.

Subentries can also be created. On page 44 we have used

```
...produce accented characters\index{characters!accented} and...
```

to get the corresponding index entry. The `!` character starts a new level. Up to three levels are possible, as in

```
Up to three levels%
\index{index!subentry!level-three}
are possible, as in ...
```

It is possible to have multiple entries, as we did on page 21 with

```
The
\index{braces!curly}%
\index{curly braces}%
curly braces
```

We may specify a command of the form `\index{`*string1*`@`*string2*`}`. In this case, *string1* determines the alphabetic position in the index, but *string2* is used as the entry. This is an extremely useful feature. For example, our index contains entries that were produced by

```
\index{bigskip@\verb+\bigskip+}
\index{eqnarray@\texttt{eqnarray} environment}
```

The first of these uses `\verb` rather than `\texttt` because of the presence of the backslash (\).

Cross-referencing within the index is easily achieved. To refer the reader from *entry1* to *entry2*, use the command `\index{`*entry1*`|see{`*entry2*`}}`. For example, we used

```
\index{full stop|see{period}}
```

in forming our index. The | character can also be used to specify a range of pages: use `\index{`*entry*`|(}` at the start of the range and `\index{`*entry*`|)}` at the end. We used `\index{index|(}` and `\index{index|)}` at the beginning and end of this section, respectively.

In order for your `\index` commands to produce the desired effect you must include the package `makeidx`; this can be done by putting the commands

```
\usepackage{makeidx}
\makeindex
```

in the preamble. Finally, put the command

```
\printindex
```

where the index is to appear—usually immediately before `\end{document}`. Figure 4.1 shows a typical setup involving these commands.

Once you have included the appropriate commands in your document, the index is generated in the following manner. Suppose the LaTeX file is called `filename.tex`. Then the first step is to run LaTeX on this file, in the usual way. In addition to the other files with extensions `pdf/dvi`, `aux`, `log`, etc., LaTeX will create `filename.idx`. (If you inspect this file, you will see that it contains the entry/page number information that defines the index.) Next, run

the program *MakeIndex* on `filename.idx`; the syntax for this may depend on your computer system, but it is likely to be

```
makeindex filename
```

MakeIndex creates the file `filename.ind`. Finally, run LaTeX once more on `filename.tex`. The `pdf/dvi` file will now include your index.

In summary, having embedded the correct commands in your document, automatic index generation is a three-stage process: LaTeX, *MakeIndex*, and then LaTeX again. If you make any changes to the `tex` file that will affect the index, then you must repeat the three stages to see the new index. The indexing process is normally carried out when the document is more or less complete.

5.6 LaTeX Through the Years

1986: First recorded use of the phrase "typographically challenged" in reference to non-LaTeX users.

1987: Student writes Ph.D. thesis completely in `verbatim` environment.

1988: Leading mathematical journal rejects manuscript on the grounds that "too many of the variables have fancy tildes over them."

1989: Typing ... instead of `\ldots` becomes a criminal offense.

1990: Number of rainforests that could have been saved if people had bothered to make full use of LaTeX previewers reaches double figures.

1991: Killer strain of LaTeX evolves, replacing the "`Rerun to get cross-references right`" message with "`Do that again and I delete your files.`"

1992: Bullet overuse receives the official status of "syndrome."

1993: Somebody finally finds a use for the $\bowtie$ symbol.

1994: Extensive testing shows that 98.3% of the time no matter which of the `[h]`, `[t]`, `[b]`, or `[p]` options is used, LaTeX will put your `table` at the end of the document.

1995: "I \heartsuit\␣\LaTeX" car stickers go on sale.

1996: Latest release of LaTeX includes the \jargonfill command, which fills the remainder of a page with impressive sounding technical phrases.

1997: Overzealous author publishes book in which every word appears in index.

1998: Positive identification of one thousandth instance of the joke \index{recursion|see{recursion}}.

1999: Survey reveals that 6 out of 10 LaTeX users think \iota will produce an extremely small space and 7 out of 10 LaTeX users think that \ominus will make something bad happen.

2000: After poor harvests, a worldwide shortage of \mathbb{R} symbols allows low-grade {I\!\!R} rip-offs to flood the market.

2001: Winner of inaugural *Backslash-Only Sentence Competition* chosen:

```
\latex \exists \to \stop \sloppy \and \dim
   \documentstyle \forall \times
```

2002: Painstaking digital forensics reveal that 90% of all customized maths/computer science department Ph.D. thesis style files are derived from a single, undocumented, and buggy, "mother file" discovered on a magnetic tape in a garage sale in California.

2003: Initial release of the BibTeX style file `bigshot.sty`, which sets gratuitous self-citations in bold font.

2004: Study shows that nobody has ever read the list-of-figures page that every Ph.D. student likes to generate in order to bump up the page count.

2005: Annual savings that for-profit academic publishers make by getting authors to produce camera-ready copy now exceeds the GDP of a small nation.

2006: Isolated tribe of LaTeX users discovered on a remote island who still pronounce it "lah-teck" and use \begin{math} ... \end{math}.

2007: International Olympic Committee declares that any city bidding to host the Olympic games must first have a valid Beamer theme named after it.

2008: Special Halloween edition of LaTeX released, in which `\phantom` creates ectoplasm.

2009: LaTeX users with small children can now invoke Parental Control Mode, which turns off `\bullet`, `\dagger`, `\kill`, `\sharp`, and all variants of `\arrow` and `\harpoon`.

2010: LaTeX users with teenage children can also disable `\bar` and `\date`.

2011: The most sought-after copies of *Learning LaTeX*, i.e., unsigned by the authors and without abusive messages to them scribbled in the margins, now fetch up to $1.75 on eBay.

2012: To attract a younger audience, LaTeX makes a "texting" mode available, with the `theorem` environment changed to `AFAIK` and with `:-)` marking the end of a proof.

2013: 3D printer misinterprets `\begin{table}`.

2014: Masters student wishing to add figures to a thesis gets a shock after Googling "graphical images with latex."

2015: Built on ground-breaking deep learning techniques, the new command `\gullible` automatically and intelligently fixes all errors in your LaTeX; try it!

2016: Keynote speaker booed off stage during opening remarks as Beamer navigation bar reveals 23 sections and 71 subsections.

2017: 25th Anniversary of LaTeX3's initial projected release date.

Appendix A

A Sample Article

On the next two pages we display the source code and the output of a short article that uses `\maketitle`, `\section`, and `\includegraphics`. We also use `\today`, which generates the current date. The page number on the title page is suppressed by placing the command

```
\thispagestyle{empty}
```

after the `\maketitle` command.

The graphical image has been centered with `\centering` (see page 53). The image has also been scaled by including the optional argument `[width=.5\linewidth]` (see page 52) to `\includegraphics`. This is preferable to specifying an absolute value, such as `[width=400mm]`.

The addresses of the authors could have been included in the title page by amending the argument of the `\author` command to

```
\author{S. Kimo\\
        McGills University\\
        Canada
           \and
        R. Poon\\
        University of Whales\\
        U.K.}
```

```
\documentclass{article}
\usepackage{graphicx}
\begin{document}

  \title{Polar Fishing}
  \author{S. Kimo \and R. Poon}
  \date{Version 3.3: \today}
  \maketitle
  \thispagestyle{empty}

\section{Introduction}\label{sec:int}

A \emph{folium} is a generic term for a leaf--shaped curve.  According
to Lawrence~\cite[page 151]{Law}, the curve defined by the equation
\begin{equation}\label{eq:f}
  \left(x^2+y^2\right)\left(y^2 + x(x+b)\right) = 4axy^2
\end{equation}
was known to Kepler in 1609 and generates a simple-, double- or
tri-folium, depending on whether $b \ge 4a$, $b = 0$ or $0 < b < 4a$,
respectively.

\section{Reparameterization}
To draw the folium defined by equation (\ref{eq:f}) in
Section~\ref{sec:int} it is convenient to change to polar coordinates
$x = r(\theta)\cos\theta$ and $y = r(\theta)\sin\theta$.  This leads to
\begin{equation}
  r(\theta) = ( 4a \sin^2\theta -b)\cos\theta,
\end{equation}
for $0 \le \theta <2\pi$, and is illustrated in
Figure~\ref{fig:f1} for the values $a=1$, $b=2$.
\begin{figure}[!h]
  \centering
  \includegraphics[width=.5\linewidth]{folium}
  \caption{The tri-folium for $a=1$, $b=2$.}
  \label{fig:f1}
\end{figure}

\begin{thebibliography}{9}
  \bibitem{Law} J.~D.~Lawrence, \emph{A Catalog of Special Plane
              Curves}, Dover Publications, New York, 1972.

\end{thebibliography}

\end{document}
```

Polar Fishing

S. Kimo R. Poon

Version 3.3: July 7, 2016

1 Introduction

A *folium* is a generic term for a leaf–shaped curve. According to Lawrence [1, page 151], the curve defined by the equation

$$\left(x^2 + y^2\right)\left(y^2 + x(x+b)\right) = 4axy^2 \tag{1}$$

was known to Kepler in 1609 and generates a simple-, double- or tri-folium, depending on whether $b \geq 4a$, $b = 0$ or $0 < b < 4a$, respectively.

2 Reparameterization

To draw the folium defined by equation (1) in Section 1 it is convenient to change to polar coordinates $x = r(\theta)\cos\theta$ and $y = r(\theta)\sin\theta$. This leads to

$$r(\theta) = (4a\sin^2\theta - b)\cos\theta, \tag{2}$$

for $0 \leq \theta < 2\pi$, and is illustrated in Figure 1 for the values $a = 1$, $b = 2$.

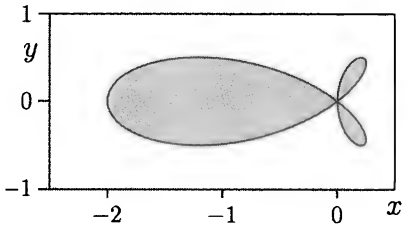


Figure 1: The tri-folium for $a = 1$, $b = 2$.

References

[1] J. D. Lawrence, *A Catalog of Special Plane Curves*, Dover Publications, New York, 1972.

Appendix B

A Sample Report

On the next page the source code is displayed for a short document written using `\documentclass{report}`. The text is similar to that in Appendix A (where it was formatted in `\documentclass{article}`), but we have used the two levels `\chapter` and `\section`.

The output, which we have shrunk to fit on a single page, should be compared with that on page 69. You should notice the following:

- The title, authors, and date (made with `\maketitle`) now occupy a page of their own.
- An optional abstract is created with the `abstract` environment (see §4.2) and normally occupies a page of its own. The abstract can be placed on the same page as the title by providing the option `notitlepage` to `\documentclass`. This has the side effect of numbering the first page, which is suppressed with the command `\thispagestyle{empty}`.
- Each chapter begins on a new page.
- The layout of the chapter number and title differs from that for section numbers and title in the `article` class.
- The equations and figures are numbered in the form `(a.b)` to signify the `b`th equation of chapter `a`.
- The `\appendix` command causes the subsequent `\chapter` to produce the chapter heading "Appendix A"; the equation is numbered (A.1).
- The references are now regarded as constituting a separate, unnumbered chapter (called Bibliography) and, because of this, start on a new page.

```
\documentclass[notitlepage]{report}
\usepackage{graphicx}
\begin{document}
  \title{Polar Fishing}  \author{S. Kimo \and R. Poon}
  \date{Version 3.3: \today}
  \maketitle
  \thispagestyle{empty}
  \begin{abstract}
    We pool our net results on multiscale imaging.
  \end{abstract}
\chapter{Introduction}\label{ch:int}
A \emph{folium} is a generic term for a leaf--shaped curve.  According
to Lawrence~\cite[page 151]{Law}, the curve defined by the equation
\begin{equation}\label{eq:f}
  \left(x^2+y^2\right)\left(y^2 + x(x+b)\right) = 4axy^2
\end{equation}
was known to Kepler in 1609 and generates a simple-, double- or
tri-Folium, depending on whether $b \ge 4a$, $b = 0$ or $0 < b < 4a$,
respectively.
\section{Reparameterization}
To draw the folium defined by equation (\ref{eq:f}) in
Chapter~\ref{ch:int} it is convenient to change to polar coordinates
$x = r(\theta)\cos\theta$ and $y = r(\theta)\sin\theta$.  This leads to
\begin{equation}
  r(\theta) = (-b + 4a \sin^2\theta)\cos\theta,
\end{equation}
for $0 \le \theta <2\pi$ and is illustrated on the left of
Figure~\ref{fig:f} for the values $a=1$, $b=2$.
\appendix
\chapter{A Related Curve}
A curve of a similar tri-folium shape is defined~\cite[page 168]{Wie}
by the equation
\begin{equation}
x^4+y^4 + 2x(x^2-y^2)=0
\end{equation}
and is shown on the right of Figure~\ref{fig:f}.
\begin{figure}[!b]
  \centering
  \includegraphics[width=.95\linewidth]{folia-2}
  \caption{Left: The tri-folium for $a=1$, $b=2$, Right: a related curve.}
  \label{fig:f}
\end{figure}
\begin{thebibliography}{9}
  \bibitem{Law} J.~D.~Lawrence, \emph{A Catalog of Special Plane
              Curves}, Dover Publications, New York, 1972.
  \bibitem{Wie} Heinrich Wieleitner, \emph{Theorie der ebenen
               algebraischen Kurven h\"{o}herer Ordnung},
              G.~J.~G\"{o}schensche Verlangshandlung, Leipzig, 1905.
\end{thebibliography}

\end{document}
```

Polar Fishing

S Kim-o R Poon

Version 3 0 July 7 2016

Abstract

We ponder our results on matters ad nauseam

Chapter 1

Introduction

A *folium* is a generic term for a leaf shaped curve. According to Lawrence [1 page 151] the curve defined by the equation

$$(x^2 - y^2)(y^2 + x(x + b)) = 4axy^2 \qquad (1.1)$$

was known to Kepler in 1609 and generates a simple double or tri-folium depending on whether $b \geq 4a$ $b = 0$ or $0 < b < 4a$ respectively

1.1 Reparameterization

To draw the folium defined by equation (1.1) in Chapter 1 it is convenient to change to polar coordinates $x = r(\theta)\cos\theta$ and $y = r(\theta)\sin\theta$ This leads to

$$r(\theta) = (-b + 4a\sin^2\theta)\cos\theta \qquad (1.2)$$

for $0 \leq \theta < 2\pi$ and is illustrated on the left of Figure A.1 for the values $a = 1$ $b = 2$

Appendix A

A Related Curve

A curve of a similar tri-folium shape is defined [2 page 168] by the equation

$$x^4 + y^4 + 2x(x^2 - y^2) = 0 \qquad (A.1)$$

and is shown on the right of Figure A.1

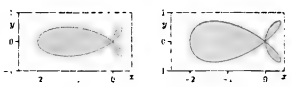


Figure A.1: Left: The tri-folium for $a = 1$ $b = 2$. Right: a related curve.

Bibliography

[1] J D Lawrence *A Catalog of Special Plane Curves* Dover Publications New York 1972

[2] Heinrich Wieleitner *Theorie der ebenen algebraischen Kurven höherer Ordnung* G J Göschensche Verlagshandlung Leipzig, 1905

Appendix C

A Sample Presentation

In the days when presentations were delivered by means of transparencies, they were usually produced by the `slides` document class (part of the original LaTeX package). The popularity of this class waned with the advent of data projectors. Several independently produced classes are now available for presentations. One such is the `beamer` document class written by Till Tantau "mainly in his spare time." The output appears in large, clear, customized fonts, and each page supports clickable navigation. An example of a `beamer` file and its output are shown on pages 76–77. Note that larger-than-normal fonts have been used for clarity.

The source file begins by specifying

```
\documentclass{beamer}
```

and is followed by the preamble in which any additional packages are loaded (many standard packages are loaded automatically). This is also a convenient location for defining commands, including those that will be used to form the title page. The main document is, as usual, enclosed in a

```
\begin{document} ... \end{document}
```

environment. The document may be divided into *sections*, which may (or may not) have *subsections*, which are, in turn, composed of *frames* that contain the material for each "slide" (with any possible overlays). Our sample document shown on page 77 comprises six frames (of which two have an overlay, so there are eight slides) and three sections, the last of which also has a subsection. We have chosen to format our presentation in the `Hannover` theme with the `dove` colortheme, as indicated in the preamble. There are, currently, around 30 themes and 20 colorthemes. These are illustrated on several websites that can be located with an Internet search engine.

With this choice of theme each slide has, in addition to the main text area, a grayed sidebar, known as the navigation bar, on the left. This shows the title, authors, and a table of contents (which is taken from the section and subsection headings). The title and author names will usually be too long for the navigation bar, so the corresponding commands have options, placed in `[...]`, for shorter alternatives.

```
\documentclass{beamer}
  \usetheme{Hannover}     % governs the format of each slide
  \usecolortheme{dove}    % governs the color scheme
  \title[Research Skills] % optional, short paper title
    {Essential Research Skills}  % long paper title
  \subtitle{How to get ahead}    % optional
  \author[DFG \& DJH]     % optional short list of authors
       {David Griffiths~\inst{1} \and Desmond Higham~\inst{2}}
  \institute{\inst{1} University of Dundee
       \quad\includegraphics[height=0.5cm]{dundee-logo-bw}
     \and \inst{2} University of Strathclyde
       \quad\includegraphics[height=0.5cm]{strath_logo}
\begin{document}
\begin{frame} %---------------------------------------- Frame 1
  \titlepage
\end{frame}
\begin{frame}{Table of Contents} %---------------------- Frame 2
  \tableofcontents
\end{frame}
\section[Verbal]{Verbal Skills}
\begin{frame}{Verbal Skills} %-------------------------- Frame 3
 \begin{enumerate}[(i)]
   \item Injecting enthusiasm probably won't do any harm.
   \item Appropriate metaphors are worth their...
   \item Before using a clich\'e, run it up the flagpole...
   \item There is no place for overemphasis,\pause whatsoever.
   \item Finish your point on an up-beat note, unless you ...
  \end{enumerate}
\end{frame}
\section[Written]{Written Skills}
\begin{frame}{Written Skills} %------------------------- Frame 4
\begin{enumerate}[(a)]
    \item<1> Many readers assume that a word will not assume...
    \item<1> If you can't afford a book on grammar, at least...
    \item<2> It has been suggested that some words are absolute,
          not relative. \textbf<2>{This is very true}
    \item<2> In terms of writing convoluted sentences, don't.
  \end{enumerate}
  \onslide<2>\textbf{N.B.} \emph{A strong ending ...}
\end{frame}%%%%%%%%%% source code for frames 5 & 6 deleted %%%%

\end{document}
```

Essential Research Skills

How to get ahead

David Griffiths [1] Desmond Higham [2]

[1]University of Dundee

[2]University of Strathclyde

July 7, 2016

Table of Contents

Verbal Skills

(i) Injecting enthusiasm probably won't do any harm

(ii) Appropriate metaphors are worth their weight in gold

(iii) Before using a cliché, run it up the flagpole and see if anybody salutes

(iv) There is no place for overemphasis,

Verbal Skills

(i) Injecting enthusiasm probably won't do any harm

(ii) Appropriate metaphors are worth their weight in gold

(iii) Before using a cliché, run it up the flagpole and see if anybody salutes

(iv) There is no place for overemphasis, whatsoever

(v) Finish your point on an up-beat note, unless you can't think of one

Written Skills

(a) Many readers assume that a word will not assume two meanings in the same sentence

(b) If you can't afford a book on grammar, at least find someone to lend one off

(c) It has been suggested that some words are absolute, not relative. This is very true

Written Skills

(b) If you can't afford a book on grammar, at least find someone to lend one off

(c) It has been suggested that some words are absolute, not relative. **This is very true**

(d) In terms of writing convoluted sentences, don't

N.B. *A strong ending is the last thing you need*

Technical Skills

1. It can be shown that you shouldn't miss out too many details
2. Some writers introduce a large number, N, of unnecessary symbols
3. Use mathematical jargon iff it is absolutely necessary
4. And avoid math symbols unless $\exists$ a good reason
5. Restrict hyphen-usage

Evaluation

$$\text{Impressiveness} = F^2 C_e \log(C_n) \int_0^T X(t)^2 G(t)\, dt,$$

where

- F: total funding
- C_e: # experimental constants
- C_n: # numerically computed constants
- $X(t)$: # research students at time t
- $G(t)$: `Gigaflop` rate at time t

Clicking repeatedly on the title in the navigation bar will cause the first/last frame to be displayed, while clicking on a section name will cause the first slide of that section to be revealed. The name of the currently displayed section is always highlighted. A number of icons are placed at the bottom right of each slide to facilitate skipping forward/backward by one page/frame/subsection or section.

The basic unit of a presentation is a `frame` environment, designated by

`\begin{frame}{`*frame title*`}...\end{frame}`

which contains the material for a "slide" and any possible overlays. The first frame has the single command

```
\titlepage
```

which builds the title page from the information defined in the preamble by the commands `\title`, `\subtitle`, `\authors`, and `\institution`. The command

```
\tableofcontents
```

in the second frame builds a table of contents from the arguments of the `\section{...}` and `\subsection{...}` commands. Note that sections are not numbered, and they have optional arguments such as

```
\section[Verbal]{Verbal Skills}
```

that contain a short form of the heading for inclusion in the navigation bar.

Lists, whether they are of the `itemize`, `enumerate`, or `description` variety (see §2.3.1), are popular in presentations. Beamer offers many different ways to uncover these in a piecewise fashion. The simplest is the `\pause` command illustrated in the third frame. The material shown in the frame will stop temporarily when this command is encountered. Clicking on a "forward" navigation button (or hitting any key, or paging down on a handheld device) will advance either to the next `\pause` or to the end of the frame. The two images on the second row of the output on page 77 show the two slides comprising the third frame. Notice that the `enumerate` environment has an optional argument `[(i)]` which specifies that the items will be numbered as small roman numerals: (i), (ii), etc. In frame 4 the optional argument `[(a)]` specifies numbering the list as (a), (b), etc.

The fourth frame illustrates a number of different ways that text and effects can be allocated to different slides. The specification `<1>` following `\item` indicates that the material in this item should only be shown on the first slide of the frame. Examples of other possible specifications are:

`\item<2-4>` show the material in this item on slides 2 to 4.

`\item<-4>` show the material in this item on all slides up to the 4th.

`\item<2->` show the material in this item from slide 2 onward.

A similar effect can be obtained outside a list environment with the command `\onslide<...>{...}`. This type of specification can also be added to font changing commands; the example we use in the fourth frame is

```
\textbf<2>{This is very true}
```

which applies bold font only during the second slide of the frame.

A comprehensive manual for Beamer is available online—see §E.5.

Appendix D

A Sample Poster

Posters are an effective means of communicating research results at meetings and conferences. To attract the attention of passersby, posters usually make the most of striking graphics, eye-catching colors, and large font sizes. Color cannot be reproduced here, so we have to depend on grayscales and the imagination of the reader. We illustrate the making of a poster with the `a0poster` document class, although we note that alternative LaTeX classes are also in use. LaTeX's logical design approach does not lend itself to dragging, dropping, and resizing elements. Hence, some trial and error is typically required. For mathematically oriented posters, this inconvenience is outweighed by the access to high-quality, pin-sharp technical typesetting.

A sample LaTeX file and its corresponding (shrunk-to-fit) output are shown on pages 82–83. Our poster is wordy and detailed. A less verbose style is more appropriate in some contexts. The option `[a0]` in the command

```
\documentclass[a0]{a0poster}
```

specifies A0 paper size (841mm×1189mm or 33.1in×46.8in). Other options are A1, A2, and A3, with the default size being A0b, a slightly larger version of A0. The default orientation is landscape—for portrait, the options should be amended to `[a0,portrait]`. The `a0poster` class also provides a set of enlarged fonts described by

```
\tiny, \scriptsize, \footnotesize, \small, \normalsize, \large,
\Large, \LARGE, \huge, \Huge, \veryHuge, \VeryHuge, \VERYHuge
```

where `\tiny` refers to a font size of 12pt and successive sizes increase by 20% up to `\VERYHuge` at 107pt ($12(1.2)^{12} \approx 107$). Size changes are invoked as described in §2.2, and a selection of available sizes is illustrated in Figure D.1. In all other respects this class behaves just as `article` (see Chapter 4).

```
\documentclass[a0]{a0poster}
  \usepackage[absolute,overlay]{textpos} % The textpos package
          % positions blocks of text at specified locations on the page
  \usepackage{amsfonts, amsmath}   % AMS packages
  \usepackage{graphicx}
  \usepackage{color}     % required for grayscales
  \usepackage{tcolorbox} % used to place frame on poster/heading
  \graphicspath{{../figures/}}     % Location of the graphics files
  \TPGrid[40mm,30mm]{24}{12}       % 40mm margin on vertical edges
                                   % 30mm margin top & bottom
        % Set width=24 - must be an integer.  24 = 3 columns of width 8
        % Set height=12.
  \TPMargin{12.5mm}  % Margin width for each column
  \parindent=0pt     % suppresses indentations for paragraphs
  \definecolor{Grey}{cmyk}{0,0,0,0.15}
  \definecolor{White}{cmyk}{0,0,0,0}
\begin{document} %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Start document
  \title{\VeryHuge  Posters in \LaTeX\\\Huge Where's the Catch?}
  \date{}\author{\LARGE\begin{tabular}{cc}
     David Griffiths & Desmond Higham \\
    \textsl{University of Dundee}& \textsl{University of Strathclyde}
                       \end{tabular} }
% First place a frame around the entire poster
\begin{tcolorbox}[height=.85\textheight,width=\textwidth,arc=20mm]
\end{tcolorbox}
    \begin{textblock}{8}(0,0)          % Positions the Heading
        \begin{tcolorbox}[arc=10mm]\maketitle\end{tcolorbox}
    \end{textblock}
    \thispagestyle{empty}                % Suppresses page numbering
    \begin{textblock}{8}(8,0)            % Photos
         \includegraphics[height=131mm]{David-bw}
         \includegraphics[height=131mm]{Des-bw}
    \end{textblock}
    \begin{textblock}{8}(16,0)    % Positions logos in the top right
         \textblockcolour{White}  % Background color for logos
              \includegraphics[height=131mm]{dundee-logo-bw}
         \quad\includegraphics[height=131mm]{strathclyde-logo-bw}
    \end{textblock}
    \textblockcolour{Grey}
    \begin{textblock}{8}(0,2.4)                              % Column 1
        \input{zombie}
    \end{textblock}
    \begin{textblock}{8}(8,2.4)                              % Column 2
        \input{pursuit}
    \end{textblock}
      \textblockcolour{Grey}
    \begin{textblock}{8}(16,2.4)                             % Column 3
       \input{polar-fishing}
    \end{textblock}
\end{document}
```

Posters in LaTeX

Where's the Catch?

David Griffiths Desmond Higham
University of Dundee University of Strathclyde

UNIVERSITY OF DUNDEE

University of Strathclyde Glasgow

Zombie Outbreak

Munz et al. [1] model a zombie outbreak involving $H(t)$ humans, $Z(t)$ zombies and $R(t)$ removed—'dead' zombies that may return as zombies. A zombie may irreversibly convert a human into a zombie but cannot be killed. A plucky human may temporarily send a zombie into the 'removed' class. The simplest version of the model takes the form

$$\begin{aligned} H'(t) &= -\beta H(t)Z(t), \\ Z'(t) &= (\beta-\alpha)H(t)Z(t)+\gamma R(t), \\ R'(t) &= \alpha H(t)Z(t)-\gamma R(t). \end{aligned}$$

The parameters control the rates at which various interactions occur:

1. $\alpha = 0.015$, the rate of zombie removal,
2. $\beta = 0.05$, the rate at which humans are converted to zombies,
3. $\gamma = 0.05$, the rate at which removed zombies reappear as zombies.

Figure 1 shows the evolution of a population that had, initially, $H(0) = 500$ humans and $Z(0) = 10$ zombies. The outcome is a complete collapse of the human population within 40 days with total zombification over a period of 100 days.

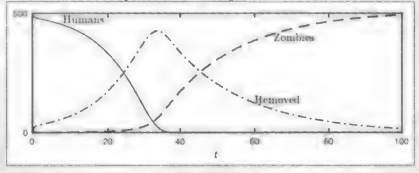


Figure 1: Ten zombies from Lenzie, near Glasgow, attack the sleepy community of Newport in Fife.

Curves of Pursuit

There are many scenarios where a pursuer has to rendezvous with a moving target. As an illustration, suppose that the target—a rabbit—follows the path $(r(t), s(t))$, defined by an Euler spiral:

$$r(t) = \int_0^{t-2} \cos(u^2)\,\mathrm{d}u, \quad s(t) = \int_0^{t-2} \sin(u^2)\,\mathrm{d}u.$$

Suppose also that the pursuer—a fox—is chasing the rabbit in such as way that it is moving at all times directly towards the rabbit. The fox's path $(x(t), y(t))$ can be shown to satisfy

$$\begin{aligned} x'(t) &= k\,(r(t)-x(t))\,/R(t), \\ y'(t) &= k\,(s(t)-y(t))\,/R(t), \end{aligned}$$

where k is the ratio of the speed of the fox to that of the rabbit and $R(t) = \left((r(t)-x(t))^2+(s(t)-y(t))^2\right)^{1/2}$ is the distance between the protagonists. Their paths are shown on the left of Figure 2 when $k = 1.1$ and the fox starts at the origin. The distance between the two adversaries is shown on the right of the figure and the demise of the rabbit is seen to occur at approximately $t = 1.75$.

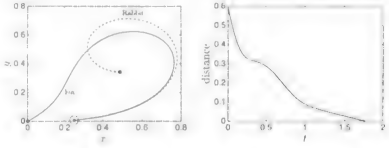


Figure 2: Left: Fox–rabbit paths. Right: Fox–rabbit separation.

Polar Fishing

A *folium*—a generic term for a leaf-shaped curve—was apparently familiar to Kepler as far back as 1609. The curves defined implicitly by the equations

$$\begin{aligned} \left(x^2+y^2\right)\left(y^2+x(x+2)\right) &= 4xy^2, \\ x^4+y^4+2x(x^2-y^2) &= 0 \end{aligned}$$

lead to similar tri-folia.

Reparameterization

The curves shown in Figure 3 were generated by transforming to polar coordinates $x = r(\theta)\cos\theta$ and $y = r(\theta)\sin\theta$ to give

$$r(\theta) = -2\cos\theta\cos 2\theta \text{ and } r(\theta) = -\frac{2\cos\theta\cos 2\theta}{1-\frac{1}{2}\sin^2 2\theta}, \quad 0 \le \theta \le \pi.$$

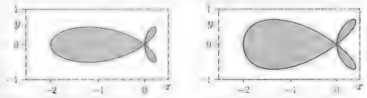


Figure 3: Tri-folium curves.

References

[1] P. Munz, I. Hudea, J. Imad and R.J. Smith?. *When zombies attack!: Mathematical modelling of zombie infection.* In J. Tchuenche and C. Chiyaka, editors, *Infectious Disease Modelling Research Progress*, pages 133–150, Nova, 2009.

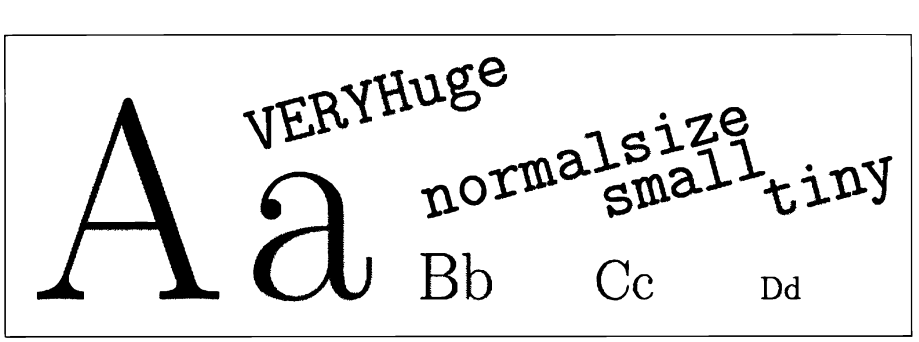


Figure D.1: Some font sizes in the `a0poster` document class.

The positioning of text on the poster is governed by the package `textpos` with options `absolute` and `overlay`. The second option is necessary to avoid the text being obscured by the frames that are placed around the heading and the poster itself (using the environment `tcolorbox` provided by the package of the same name). The `textpos` command

```
\TPGrid[40mm,30mm]{24}{12}
```

places margins of 40mm at the left and right sides and 30mm at the top and bottom and creates a virtual grid on the remaining area that has a width of 24 units and a height of 12 units (these must be integers). The top left and bottom right corners of the poster then have coordinates $(0,0)$ and $(24,12)$, respectively. Our poster consists of a 2×3 array of text blocks, each having a width of 8 units, created with an environment of the form

```
\begin{textblock}{8}(x,y)  ... \end{textblock}
```

where (x,y) are the coordinates of its upper left corner. The command

```
\TPMargin{12.5mm}
```

places margins on each of the columns to avoid text from one block running into that from a neighbor. The text blocks in the top row have top left corners with coordinates $(0,0)$, $(8,0)$, and $(16,0)$. The first of these blocks contains the title, which is made using the `\title{...}`, `\author{...}`, `\date{...}`, and `\maketitle` commands described in §4.2. Notable features are the changes in font size, the `tabular` environment within `\author{...}`, used to include the appropriate affiliations, and the commands

```
\begin{tcolorbox}[arc=10mm]
    \maketitle
\end{tcolorbox}
```

which place a frame (with rounded corners of radius 10mm) around the title. The overall depth of the title block is found (by experimentation) to be 2.4 units, and the sizes of the images in the remaining top row blocks are adjusted appropriately (by further experimentation). The command

```
\thispagestyle{empty}
```

placed after `\maketitle`, suppresses the page number.

Text blocks in the second row have top left corners with coordinates $(0, 2.4)$, $(8, 2.4)$, and $(16, 2.4)$. The text for each column is input from separate files, not shown here. For the first column on Zombie Outbreaks the commands are

```
\textblockcolour{Grey}
\begin{textblock}{8}(0,2.4)
    \input{zombie}
\end{textblock}
```

The first command specifies the background color of the block (and subsequent blocks, unless changed), where `Grey` is defined in the preamble by

```
\definecolor{Grey}{rgb}{0.85,0.85,0.85}
```

A gray shade is produced when the three numerical red, green, and blue arguments are equal, with `{1,1,1}` being white and `{0,0,0}` being black. Because we are essentially using an `article` class, material in each block is grouped using the standard `\section{...}`, `\section*{...}`, `\subsection{...}`, etc., commands (see §4.3). The text in these blocks is set in `\Large` font (44% larger than `\normalsize`) so that it remains legible when shrunk to fit onto our page size.

Appendix E

Internet Resources

Resources available on the Internet fall into the broad categories of documentation, software, hypertext help, and support forums that feature discussion threads. We shall not attempt the impossible task of giving comprehensive listings but will provide information that those interested may pursue.

E.1 CTAN

The Comprehensive TEX Archive Network (CTAN), which can be accessed at

`http://www.ctan.org`

is the primary source of information relating to LATEX. CTAN makes available free versions of the complete LATEX software distribution suitable for Windows, Mac OS X, and Unix/Linux operating systems through TEXLive. There are also tailored versions for Windows users (MiKTEX or proTEXt) and for Mac OS X users (MacTEX). They also hold answers to frequently asked questions and over 5,000 user-supplied packages.

The archive can be searched or browsed. In order to keep network load to a minimum, the same information is held at a number of "mirror" sites distributed worldwide. The link `http://mirror.ctan.org/` will automatically redirect you to a suitable mirror. Redirection will only take place if the mirror site is up-to-date.

The software and documentation held by CTAN is also available on CD-ROM, which is distributed by the TEX Users Group (TUG—see §E.3) and is free to members.

The TEX Catalogue Online (CTAN Edition) by Graham Williams lists "5,141 TeX, LaTeX, and related packages and tools" (as of June 2016) and may be found at `http://texcatalogue.ctan.org`.

E.2 The LATEX Project

The LATEX Project is a team headed by Frank Mittelbach that looks after the LATEX kernel and its key packages. Its website (`https://latex-project.org`)

provides details of how to acquire the software and has extensive links to online documentation. There are further details of LaTeX books such as [1, 2, 6, 8, 9], most of which are written by members of the team, with sample pages, eBook versions, errata, and translations into German, French, and Spanish.

The LaTeX Project site also maintains information about LaTeX3, a volunteer project funded by donations, working toward the next version of the software.

E.3 TUG

The TeX Users Group (TUG) is a not-for-profit organization that offers advice and information about TeX-related matters via the website

`https://tug.org/`

It also has local user groups in many countries throughout the world. There is a nominal fee for membership of the organization, but technical information is available from their web page free of charge (as is its journal, The PracTeX Journal).

E.4 {TeX}

TeX-LaTeX Stack Exchange at `http://tex.stackexchange.com/` is a question and answer site for users of TeX, LaTeX, ConTeXt, and related typesetting systems.

E.5 Documentation

In this section we describe some documentation that comes in the form of `tex` files (or preprocessed in `pdf` formats). Most of the files come with the standard LaTeX distribution and are updated periodically with the file names remaining unchanged. We strongly recommend, therefore, that you search for them when they are needed on the CTAN site (or one of its mirrors) in order to ensure that you have the most recent version.

`a0_eng.pdf`
: Documentation for `a0poster`, Version 1.22b, by Gerlinde Kettl and Matthias Weiser. Provides large fonts for producing A0-sized posters (see Appendix D). A German version, `a0_ger.pdf`, is also available.

`amsldoc.pdf`
: American Mathematical Society's *User's Guide for the* `amsmath` *package*, Version 2.0, 1999 (revised 2002).

`babel.pdf`
: *Babel* by Johannes L. Braams (original author) and Javier Bezos (current maintainer). Version 3.9m, 2015.

  Describes LaTeX support for non-English languages. Gregorio [4] has written a user-friendly introduction.

`beameruserguide.pdf`
: *The* BEAMER *class* by Till Lantau, Joseph Wright, Vedran Miletić. User guide for Version 3.36, 2015. See Appendix C.

`bm.pdf`
: *The* `bm` *Package* by David Carlisle, with support by Frank Mittelbach. Version 1.1c (2014).

`btxdoc.pdf`
: BibTeX*ing* by Oren Patashnik. Version 0.99d, 1988.

  Create bibliographies from a common database (see §5.4.1).

`epslatex.pdf`
: *Using Imported Graphics in LaTeX and pdfLaTeX* by Keith Reckdahl. Version 3.0.1, 2006. Discusses inclusion of `eps`, `pdf`, `jpeg`, and `png` files as well as ways of customizing the `figure` environment and its caption.

`epstopdf.pdf`
: *The* `epstopdf` *Package* by Heiko Oberdiek. Version 2.5, 2010.

  "This package adds support of handling `eps` images to package `graphics` or `graphicx` with option `pdftex`. If an `eps` image is detected, `epstopdf` is automatically called to convert it to `pdf` format."

`geometry.pdf`
: *The* `geometry` *Package* by Hideo Umeki. Version 5.6, 2010.

  "This package provides a flexible and easy interface to page dimensions. You can change the page layout with intuitive parameters. For instance, if you want to set a margin to 2cm from each edge of the paper, you can type just `\usepackage[margin=2cm]{geometry}`."

`grfguide.pdf`
: *Packages in the "graphics" bundle* by D. P. Carlisle (1999). A user manual for the packages `color`, `graphics` and the extended graphics package `graphicx` (§5.3).

`latexsheet.tex`
: *LaTeX 2ε Cheat Sheet* by Winston Chang, 2014. A concise list of LaTeX commands designed to be printed on two sides of a sheet of A4 paper (not available on CTAN).

`makeindex.tex`

Makeindex: An Index Processor for LaTeX by Leslie Lamport (1987). This describes the version for LaTeX 2.09 but applies equally to the current version of LaTeX.

`miktex.pdf`

MiKTeX 2.9 Manual by Christian Schenk. Revision 2.9.5845, 2016. A distribution of LaTeX designed for use under Microsoft Windows.

`natbib.tex`

Natural Sciences Citations and References by Patrick W. Daly. Version 8.31b, 2010. Describes the `natbib` package for alternative citation formats for bibliographies.

`testmath.tex`

Sample Paper for the `amsmath` *Package*, Version 2.0, 1999, American Mathematical Society.

`textpos.pdf`

Textpos: Absolute Positioning of Text on the Page by Norman Gray (`http://nxg.me.uk`). Documentation for Version 1.7j, 2014 (see Appendix D).

`usrguide.pdf`

LaTeX 2ε for Authors, written by the LaTeX 3 Project Team, 2015. "This document describes how to take advantage of the new features of LaTeX, and how to process your old LaTeX documents with LaTeX 2ε. However, this document is only a brief introduction to the new facilities and is intended for authors who are already familiar with the old version of LaTeX. It is not a reference manual for LaTeX 2ε nor is it a complete introduction to LaTeX."

`WelcomeToMacTeX.pdf`

Welcome to MacTeX by Bob Kerstetter of the TeX User's Group. Version 2.0, 2012 (not available on CTAN).

Bibliography

[1] Michel Goossens, Frank Mittelbach, Sebastian Rahtz, Denis Roegel, and Herbert Voß, *The LaTeX Graphics Companion*, 2nd Edition, Addison-Wesley, Reading, Massachusetts, 2008. ISBN 978-0-321-50892-8.

[2] Michel Goossens and Sebastian Rahtz, with Eitan M. Gurari, Ross Moore, and Robert S. Sutor, *The LaTeX Web Companion: Integrating TeX, HTML, and XML (Tools & Techniques for Computer Typesetting)*, Addison-Wesley, Reading, Massachusetts, 1999. ISBN 0-201-43311-7.

[3] George Grätzer, *More Math into LaTeX*, 4th Edition, Springer, 2007. ISBN 13-978-0-387-32289-6.

[4] Enrico Gregorio, *Babel, how to enjoy writing in different languages*, The PracTeX Journal, 2007, No. 1.

[5] Nicholas J. Higham, *Handbook of Writing for the Mathematical Sciences*, 2nd Edition, SIAM, Philadelphia, 1998. ISBN 0-89871-420-6.

[6] Helmut Kopka and Patrick W. Daly, *Guide to LaTeX*, 4th edition, Addison-Wesley, Reading, Massachusetts, 2004. ISBN 0-321-17385-6.

[7] Donald E. Knuth, *The TeXbook*, Addison-Wesley, Reading, Massachusetts, 1986. ISBN 0-201-13448-9.

[8] Leslie Lamport, *LaTeX: A Document Preparation System. User's Guide and Reference Manual*, 2nd Edition, Addison-Wesley, Reading, Massachusetts, 1994. ISBN 0-201-52983-1.

[9] Frank Mittelbach and Michel Goossens, with Johannes Braams, David Carlisle, and Chris Rowley, *The LaTeX Companion*, 2nd Edition, Addison-Wesley, Reading, Massachusetts, 2004. ISBN 0-201-36299-6.

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